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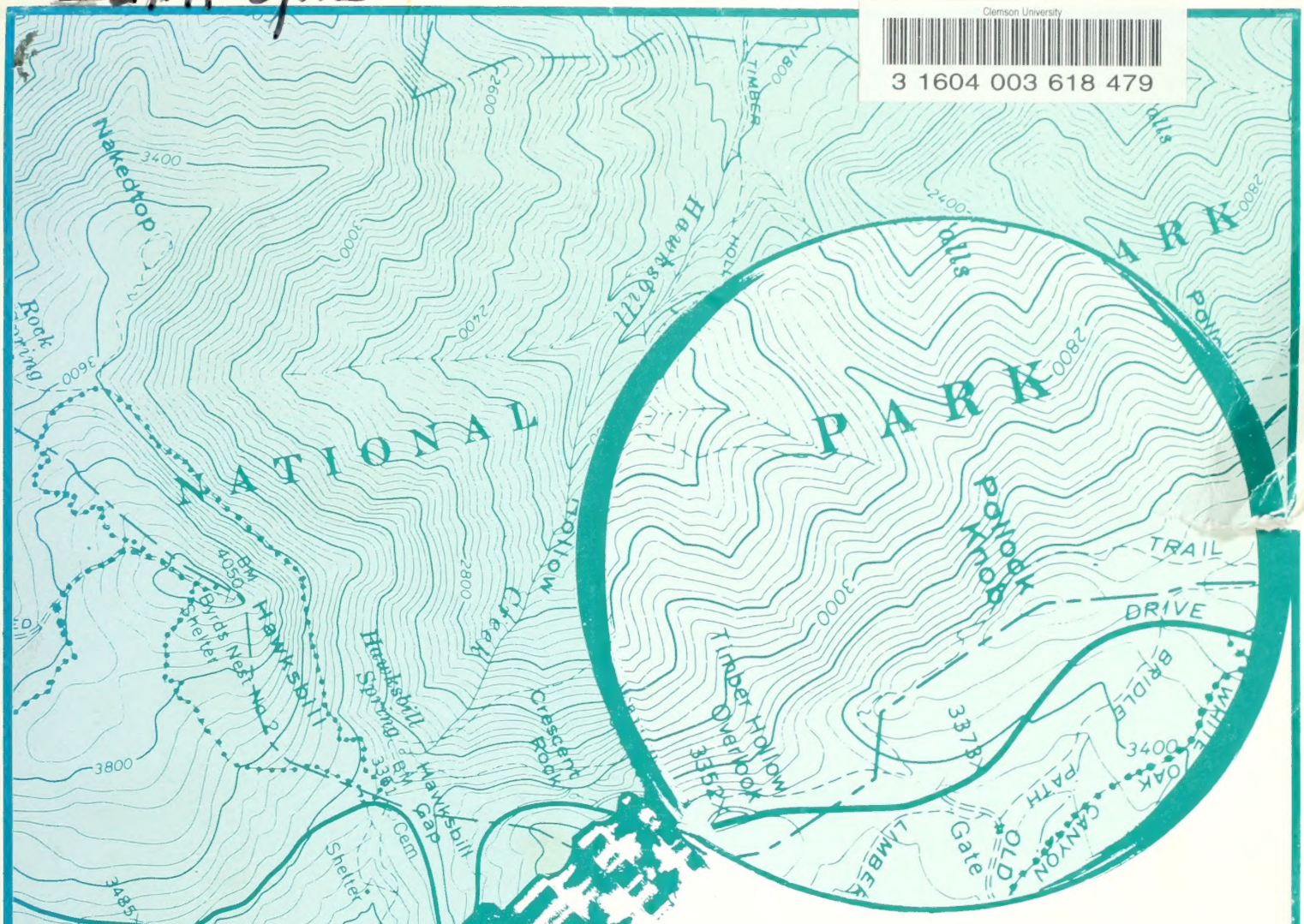

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First Conference on Scientific Research in the National Parks

Volume II

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As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in Island Territories under U.S. administration.

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ATMOSPHERIC MEASUREMENTS AT GRAND CANYON[1]

R. G. Layton, W. C. Malm, K. D. O'Dell, and W. R. Willis[2]

Measurements of air quality have been made on the rim and inside the Grand Canyon of the Colorado since 1972. The types of measurements include:

1. Aitken nuclei concentrations
2. Aerosol particulate concentrations with trace element and sulfate concentration analysis using High Volume samplers
3. Particle size distribution
4. Optical extinction measurements
5. Wind speed and direction
6. Temperatures

Measurements 1 and 2 were made at two locations, South Rim Visitor Center and Phantom Ranch (Colorado River). Measurements 3 and 4 were primarily at South Rim. Measurements 5 and 6 were made at the South Rim, two locations on the Tonto Plateau (inner canyon), and at Phantom Ranch. All air quality measurements indicate a very clean air in the Grand Canyon with seasonal and annual fluctuations. For example, aerosol mass loadings vary from 5 to 40 $\mu g/m^3$ while typical Aitken nuclei concentrations range from 400 to 3000 per cm^3. The extremely clean air represents an important quality of this park and it should be monitored on a regular and continuing basis.

INTRODUCTION

The national parks present a unique challenge to the management of natural resources. Each park is set aside due to special qualities it possesses and ideally is managed such that present visitors use is consistent with preservation of the environment for future generations. Effective management must be based upon a clear understanding of which environmental qualities are important for satisfying visitor experience and upon a realistic assessment of the parameters which can affect each of these qualities.

Since the observation of scenery is an important part of the visitor experience in many national parks, air quality makes an important contribution to their total experience in the park. This is especially true in the Grand Canyon National Park where the possible changes in air quality have recently received much publicity as a result of the construction and planning of large coal fired power plants in the surrounding region. This controversy well illustrates the problems encountered when arguments are based on subjective observations rather than on well defined objective measurements.

Grand Canyon National Park shares another problem with many other of the parks, i.e. current standard air quality measurements were developed for quite different situations and objectives than are usually relevant for the national parks. In the polluted air of many of our cities visibility may be measured in city blocks and the concentrations of pollutants may approach levels injurious to health while in the Grand Canyon the visibility is measured in hundreds of kilometers and pollutants are often near the threshold of detection. Additional constraints are imposed by the extreme temperature fluctuations found in the canyon and by the wilderness character of the region.

After consultation with National Park officials, an exploratory program was undertaken to determine the types of measurements which (1) would be of value, (2) could be undertaken with a minimum perturbation of the environment, (3) would provide a series of objective measurements against which future data could be compared. In the following sections we will present the results of this program including the types of air quality measurements that we have made in the Grand Canyon and the results which have been obtained, together with our ideas of the need for future research.

MEASUREMENTS

Most of the Grand Canyon is a rather inaccessible wilderness. Any measurements made in the canyon must therefore be made with portable self-contained instrumentation. The one exception is at Phantom Ranch where water and electric power are available. Fortunately, although several persons live there and the campground is heavily used, the area is managed to minimize the impact upon the environment. Numerous measurements taken in the immediate vicinity of Phantom Ranch or the River Ranger Station reveal no striking differences from those taken at more remote inner canyon locations as long as reasonable care is taken to avoid obvious sources of pollution. The inner canyon data presented in this paper were all obtained at or within a few kilometers from Phantom Ranch. The rim data were obtained at or near Grand Canyon Village. Further discussion on the methods, techniques, and their significance is contained in Walther, et al., 1974.

The most complete set of data consists of 722 readings of Aitken nuclei concentrations taken in the canyon over a span of five years. The results of these measurements are presented in Figures 1 - 3. The data of Figure 4 were obtained in remote areas in the vicinity of Page, Arizona and are presented for comparison.

It is tempting to observe from the high 1976 concentrations (Figure 1) the air quality must be deteriorating, however further study reveals that 1972 and 1975 are quite similar. 1976 and 1973 are significantly different from 1972 and 1975 (90% confidence interval) but these clearly reflect no obvious long term trend for either better or worse air quality--a conclusion that would not be evident if the 1972 data were missing.

Analysis by season (Figure 2) indicates only one significant change. Fall seems to be a cleaner time than other seasons. An examination of the data reveals that nearly all of the data points for Fall were obtained in 1975. Since the rest of 1975 is in no way exceptional, it seems probable that the data reflect a real phenomena, however we have no ready explanation for its cause.

[1]We are grateful for the assistance of Roy Starkey, USGS; Phil Hecker, NPS; and officials of Grand Canyon National Park for their aid and support in obtaining this data. The Page data was obtained under the Lake Powell Research Project (RANN).

[2]Northern Arizona University, Flagstaff, Arizona 86011.

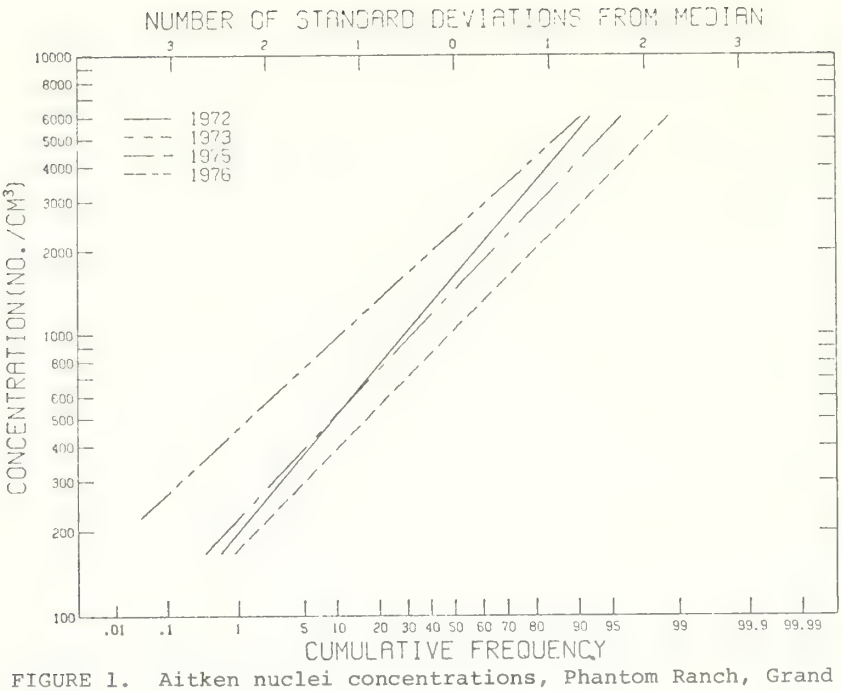

FIGURE 1. Aitken nuclei concentrations, Phantom Ranch, Grand Canyon National Park, plotted by year.

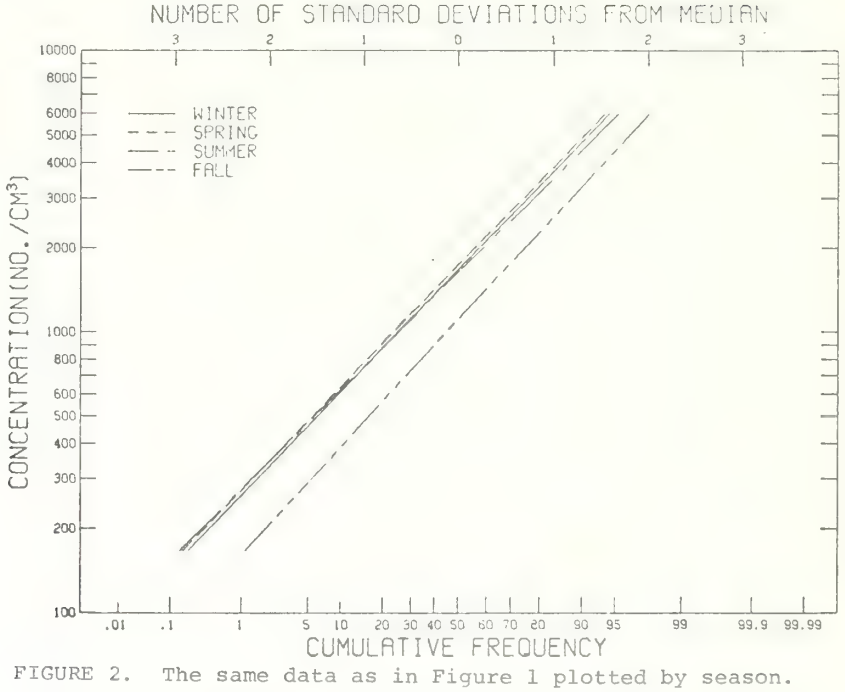

FIGURE 2. The same data as in Figure 1 plotted by season.

Two wind roses are given in Figure 5. The data for these were obtained from a portable weather station operated near the Kaibab trail on the Tonto Plateau. A comparison with the seasonal Aitken nuclei plots suggests that wind direction is not very significant in determining the Aitken nuclei concentration in the canyon.

High volume sampling at Phantom Ranch (bottom of the canyon) has been carried out since 1973. A filter was run a few hours each day for a period of several weeks; typically a run would be for four hours a day over a two week period. In addition a high volume sampler was operated from January to June of 1975 on a similar schedule at the visitor center on the rim. The results of particulate analysis of these filters is shown in the first two rows of Table 1. These filters were also analyzed for their sulfate content and the results are shown in the last column of the table. For comparison, results of high volume sampling at Grand Canyon Village by the Arizona Department of Health Services are shown in the last two rows of the table.

Although some differences do occur in the data these are fairly insignificant when the absolute sizes are considered. For here it is seen that all data indicate an extremely clean atmosphere. The worst case of particulate loading at Phantom Ranch is much better than an average result in an urban area. It must also be pointed out that a considerable amount of dust can be in the air in the dry season and that the maximum particulate loading at Phantom Ranch occurred in May of 1974, that is in the dry season. The lowest reading

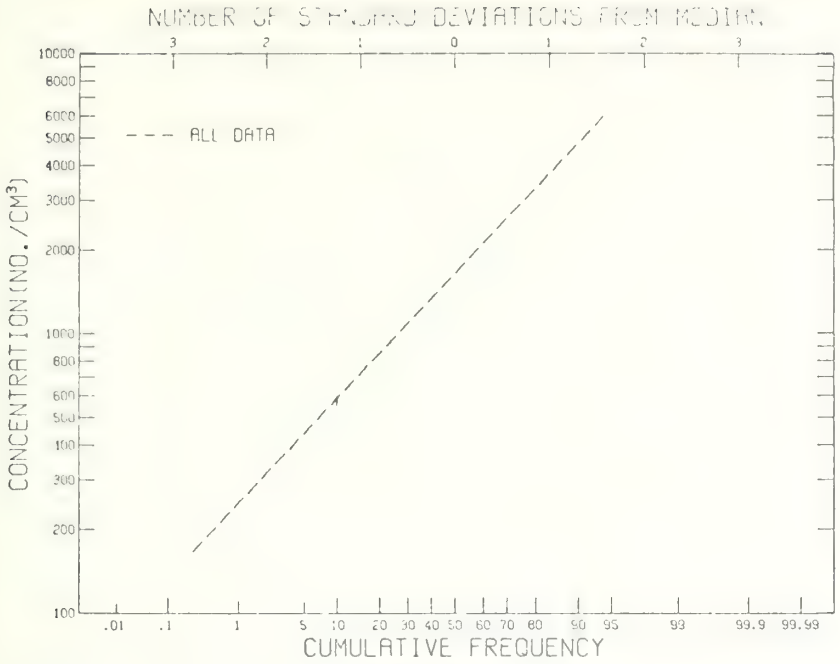

FIGURE 3. The total of the data for Figure 1.

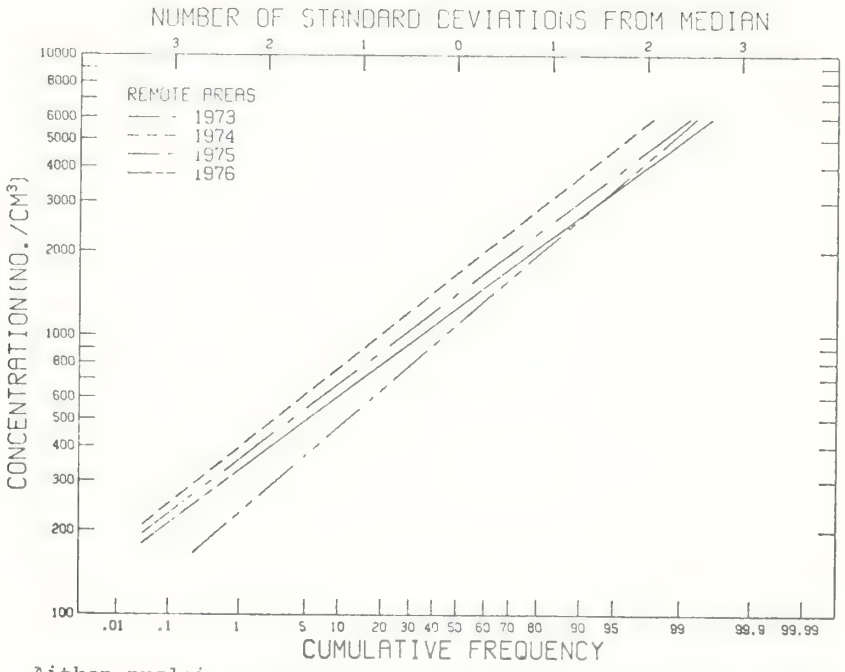

FIGURE 4. Aitken nuclei measurements, remote areas near Page, Arizona.

occurred in November of 1974 which was a moist period in the area.

An aerosol size distribution measurement indicated a typical Junge distribution; no further investigation of the size distribution has been made. At the same time these high volume samplings were going on a laser transmissometer was measuring the transparency of the air between Phantom Ranch and the South Rim. The results of these measurements (O'Dell and Layton, 1974) have been corrected for various optical problems and an average visible range of 155 Km has been measured for the red light of the laser used. This is the average of 18 readings taken intermittently between February 1973 and September 1974. The lowest reading was 101 Km and the highest was 247 Km.

The laser transmissometer, with the Grand Canyon equipment configuration (Malm amd O'Dell, 1975), gives a lower limit to the visual range, i.e. the visibility will be equal to or greater than that visual range measured by the transmissometer. These measurements then, indicate a clean Grand Canyon atmosphere.

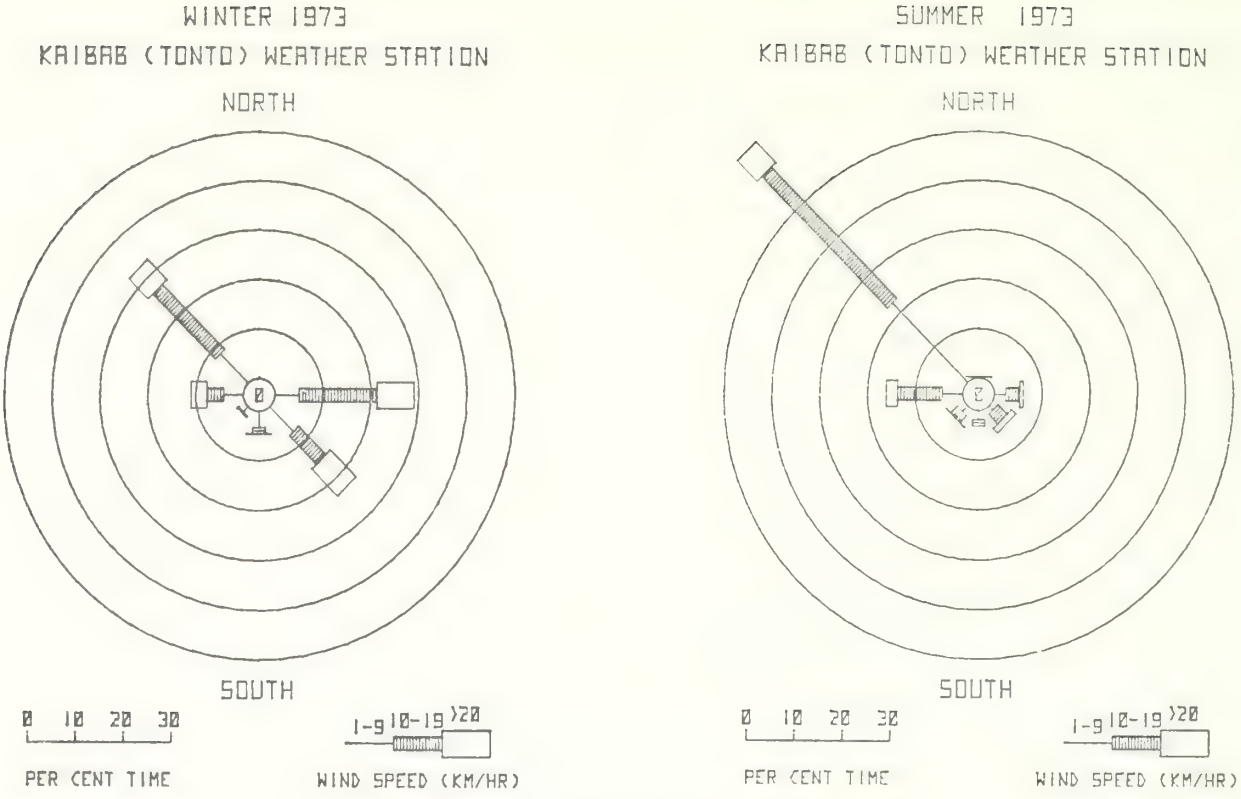

FIGURE 5. Inner canyon winds.

TABLE 1. High volume sampling results.

	Particulates ($\mu g/m^3$)			Sulfates ($\mu g/m^3$)
	Geom. mean	Highest	Lowest	Geom. mean
Phantom Ranch 1973-74-75	13.0	40	3.0	1.7
Rim Jan.-June 1975	12.9	24	6.5	2.5
Rim[a] all of 1975	14	87	-	2.2
Rim[a] 1973-74-75	16	-	-	-

[a]Taken from Air Quality Data for Arizona 1975, Arizona Department of Health Services July 1976. These are 24-hour samplings.

SUMMARY

Measurements have been made since 1972 of the air quality in Grand Canyon National Park on the rim and in the canyon. These include Aitken nuclei, high volume sampler determinations of total aerosol mass, optical extinction measurements, and some related meteorological variables. All measurements indicate an exceptionally clean atmosphere and no clear trend is evident in the five years of data now on hand. The extreme clarity of the atmosphere represents a significant part of the total visitor experience and should be monitored on a more formal and regular basis.

LITERATURE CITED

O'DELL, K. D. and R. G. LAYTON. 1974. Visibility Studies in the Grand Canyon. Plateau. Vo. 46, No. 4, Spring 1974, p. 133-134.

WALTHER, E. G., M. D. WILLIAMS, R. CUDNEY, W. MALM. 1974. Air Quality in the Lake Powell Region. Lake Powell Research Project Bulletin. Number 3, Aug. 1974. (Copies obtainable from Jeni M. Varady. Institute of Geophysics and Planetary Physics. University of California. Los Angeles, CA 90024.)

RADON 222 AND AIR EXCHANGE IN THE CARLSBAD CAVERNS[1]

Marvin H. Wilkening[2]

A series of measurements of ^{222}Rn concentrations in the Carlsbad Caverns was begun in February 1973 for the purpose of exploring the natural circulation within the caverns and estimating exposure levels to people visiting or working in the caves. Preliminary results of this work were first reported by the author at an international symposium on Areas of High Natural Radioactivity in Pocos de Caldas, Brazil (Wilkening 1975), and in a detailed publication the following year (Wilkening and Watkins 1976). Earlier studies made in a mine tunnel west of the main campus at Socorro clearly indicated that unventilated, underground cavities contained relatively high levels of radon and its daughter products even though the surrounding rocks and soil possessed only normal trace amounts of ^{238}U and ^{226}Ra (Wilkening 1962).

In this paper the levels of radon concentrations found in caves are explained, with special emphasis on how natural ventilation processes affect the amount of radon present.

RADON FROM ROCKS AND SOILS

Radon is unique among the nuclides in the naturally occurring radioactive series because of its inert gas character. Radon 222 atoms are formed at or near the surface of mineral grains in rocks and soils as the result of the decay of the parent ^{226}Ra atoms. An abbreviated form of the uranium series and the short-lived ^{222}Rn daughters is given in Table 1.

Once formed the radon atoms are free to diffuse through the interstices between mineral or soil particles, where they become a minor constituent of the soil gas.

The concentration of ^{222}Rn in soil capillaries several meters below the earth's surface exceeds that of ordinary outdoor air by a factor of the order of a thousand. Hence, a steady "current" or flux of ^{222}Rn atoms proceeds from soil to air at the earth-air interface. Eddy diffusion transports the radon from near the earth's surface to high levels in the earth's atmosphere through normal mixing processes in an effective manner, compared with the soil where molecular diffusion is the dominant transport process (Clements and Wilkening 1975).

Factors which influence the flow of radon atoms from the soil to the air are:

1) The concentration of the parent ^{222}Ra in the soil and rocks.

2) The "emanating power" which is the fraction of ^{222}Rn atoms which escape the mineral grains within or on which they are formed. This may vary from only about 0.02 for recent lavas to 0.7 for well-developed, fine-grained soils.

3) The porosity of the soil or rock material.

4) Atmospheric pressure differentials across the interface.

5) The degree of water saturation.

6) Other meteorological influences.

Quite apart from anomalous concentrations such as those found in the Grants uranium belt of west central New Mexico, uranium and radium are distributed widely in the earth's crust. Acidic igneous rocks contain ^{238}U averaging about 3.0 parts per million by weight, while limestone and other sedimentary rocks such as those in which the Carlsbad Caverns are found average only about 1.3 ppm. ^{226}Ra concentrations are normally about one part per billion in crustal rocks (Eisenbud 1973). Preliminary analyses of soil samples from the Carlsbad Caverns show ^{226}Ra concentrations ranging from 1 to 4 pCi/g of soil. The relatively high values of ^{222}Rn found in these and similar caves are not due to any unusual concentrations of uranium and radium in the surrounding rock formation. The radon originates from the minute quantities of these substances that occur naturally on and within the interior surfaces of the caves.

RADON IN AN UNDERGROUND CAVITY

The radon levels expected in an underground cavity are affected by the factors shown in Fig. 1. When the system reaches equilibrium, the net flux of ^{222}Rn atoms from the walls is balanced by the losses due to radioactive decay and the ventilation process. In the latter case, radon-rich air within the cavity is replaced by air from outside having a low radon content. For a cavity of interior surface S and volume V, this would be

$$E = \lambda VC + Q(C - C_{od}) \qquad (1)$$

where E is the net inward flux of atoms per second for each square meter, λ is the decay constant for ^{222}Rn, C and C_{od} are the ^{222}Rn concentrations within the cavity and outdoors respectively in atoms of ^{222}Rn per cubic meter, and Q is the airflow in cubic meters per second.

If one brings air of very low concentration from out-of-doors ($C_{od} \cong 0.2$ pCi/l) relative to that within the cave ($C \cong 40$ pCi/l), C_{od} can be neglected and (1) can be solved for the radon concentration giving

$$C = \frac{E}{\lambda V + Q} \qquad (2)$$

The radon concentration is seen to depend inversely upon the sum of λV and the air exchange rate Q as well as directly upon the net inward flux, E. The radon concentration could be calculated for

[1]The assistance and willing cooperation of Superintendent Donald Dayton; Chief of Technical Services Philip Van Cleave; Dr. Gary Ahlstrand, Charles Peterson, Ron Kerbo, and others of the Carlsbad Caverns National Park staff are gratefully acknowledged. Sincere appreciation is extended to David Watkins, Daniel Gaeddert, Dr. David Raymond, and students and staff of the Radon Laboratory of New Mexico Tech, who have helped with data taking and analysis of samples. This work was supported in part by a grant from the National Science Foundation.

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TABLE 1. The uranium series and the short-lived daughter of radon.

The Uranium Series		Short-lived Radon Daughters			
	Half-life			Particle	Half-life
Uranium 238	4.5×10^9 y	Radon	222	α	3.82 d
Four daughters		Polonium	218*	α	3.05 m
Radium 226	1620 y	Lead	214	β	26.8 m
Radon 222	3.82 d	Bismuth	214*	β	19.7 m
Four short-lived radon daughters (see table at right)		Polonium	214	α	1.6×10^{-4} s
Lead 210	22 y	* Branching ratios make up less than 0.04% of the total disintegrations and are omitted.			
Two intermediate-lived daughters					
Lead 206	Stable				

the simple system shown in Fig. 1 if the physical dimensions of the cavity were known and E and Q are measured.

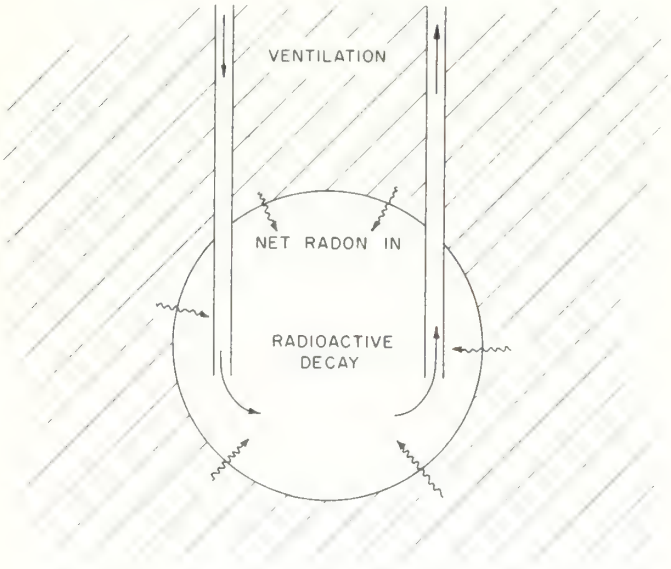

FIGURE 1. Factors governing the radon balance in an underground cavity.

THE CASE FOR THE CARLSBAD CAVERNS

The Carlsbad Caverns obviously have a very complicated geometry compared with the simple case treated above. The cave volume V, its internal surface area S and the natural circulation Q are not known. Advantage is taken of the following factors.

1) The radon concentration C will reach its maximum value C_{max} when $Q = 0$, i.e., when there is no natural ventilation. This condition is approached in the summer when the air temperature within the cave is well below the average, aboveground, nighttime temperatures.

2) When the above condition does not prevail, as in the winter months when outdoor air is colder and hence heavier than cave air, the rate of air exchange is assumed to depend linearly upon the main minimum daily outdoor temperature, θ, for all temperatures below the constant cave temperature of approximately 14°C. These conditions when substituted in equation (2) yield

$$\frac{Q(\theta)}{\lambda V} = \frac{C_{max}}{C} - 1 \qquad (3)$$

Values of

$$\frac{Q(\theta)}{\lambda V}$$

calculated from equation (3) are given in Table 2 along with the mean minimum temperature for the four days prior to and including the day of the sampling missions.

TABLE 2. Values of $Q(\theta)/\lambda V$ calculated from Eq(3).

Date	Outdoor 5-day mean min. temp (°C)	Mean ^{222}Rn (pCi/l)	$Q(\theta)/\lambda V$
Jan 75	-3.3	14	3.30
Feb 73	-0.6	16	2.75
Oct 73	10.0	36	0.67
Aug 74	18.9*	48	0.25
Jul 76	16.0*	60	0.0

*All temperatures above the mean cave tenperature of 14°C are assumed to yield no mixing and, hence, maximum ^{222}Rn concentrations within the cave.

After computing monthly mean minimum temperatures for outdoor air at the Caverns from NOAA records (1969-74), values of

$$\frac{Q(\theta)}{\lambda V}$$

are linearly interpolated from the measured data of Table 2 and substituted in equation (3).

The resulting projection for ^{222}Rn concentrations in the main portion of the Carlsbad Caverns is plotted in Fig. 2. Within the limits of error, $Q(\theta) = 0$ when the mean minimum outdoor temperatures are greater than or equal to the cave temperature, which occurs ordinarily during the months of June through August. Fig. 2 gives an estimate of the annual variation of ^{222}Rn concentrations in the Caverns. The average concentration for the year is 39 pCi/1. The ^{222}Rn levels shown in Fig. 2 are generally higher in the summer months than given by Wilkening and Watkins (1976). The chief difference is due to a higher value of C_{max} (60 pC/1) measured in late July 1976.

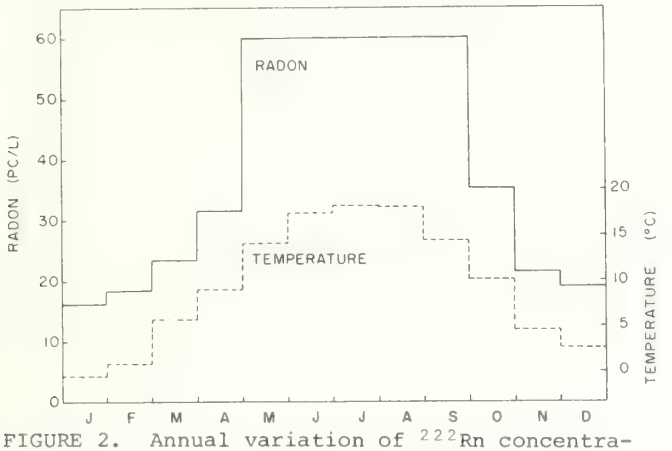

FIGURE 2. Annual variation of ^{222}Rn concentration in Carlsbad Caverns as calculated from the model. Average monthly minimum temperatures are given in the dashed curve.

It should be emphasized that the prediction based on this simple model could have large errors in the transition months in the fall or spring when the mean minimum daily temperature departs markedly from the monthly mean minimum temperature used in the model. Some fluctuation in ^{222}Rn concentration can be expected due to atmospheric pressure changes such as those preceding passage of cold fronts or other major weather disturbances. Such influences have been documented by Clements and Wilkening (1975) for the earth-air interface and by Trout (1975) in his study of ^{222}Rn concentrations in Jurnigan Cave.

RADIATION EXPOSURE LEVELS

While it is not the purpose of this paper to examine in detail the internal radiation dose received by persons entering the Caverns for various lengths of time, it is clear that when radon levels comparable to those given in Fig. 2 are reached, these matters should be pursued. Radiation protection for both occupational and non-occupational exposure is the concern of a number of different agencies.[3]

For occupational exposure the maximum is generally taken as 4 Working Level Months (4 WLM) per year where the Working Level (WL) is defined as "any combination of radon daughters in air that will result in the ultimate emission of 1.3×10^5 Mev of potential alpha energy." This value is derived from the alpha energies released by the total decay of the short-lived daughters at equilibrium with 100 pCi of ^{222}Rn per liter of air. The 4 WLM exposure is equivalent then to that received by a person working 168 hours per month for 4 months in an environment where the ^{222}Rn concentration is 100 pCi/1 (1 WL) or 33 pCi/1 (0.33 WL) for a year provided that the short-lived daughters of ^{222}Rn are present in equilibrium amounts. It is the daughters made up of isotopes of polonium, lead, and bismuth that represent the physiological hazard in the respiratory tract when inhaled and not the radon *per se*.

The concentration of ^{222}Rn in pCi/1 can be converted to Working Levels if allowance is made for the degree of equilibrium that exists between the parent radon and its short-lived daughters. Measurements made by USDI-MESA (1975, 1976) showed that the daughters were present to the extent of 72% of the equilibrium value. Using the 39 pCi/1 concentration as the mean estimated annual value from Fig. 2 and the 72% equilibrium value yields a Working Level of 0.28 for personnel working regularly in the Caverns. In the present work the daughters were found to be present to the extent of only 26% in the Pump Room on 26 July 1976. Actually the equilibrium figure can be expected to vary in the range of about 20-90%. Hence, the average annual Working Level based upon the limited ^{222}Rn measurements made to date could vary from 0.08 to 0.35 depending upon the degree of equilibrium. More study of this problem needs to be made.

The mean value of Working Level Measurements made in November of 1975 and again in August of 1976 in the Main Caverns by the MESA group are 0.31 WL and 0.34 WL respectively, which fall in the upper part of this range. Ahlstrand (1976) is reporting in this volume on the results of the direct measurement of daughter products collected on filters which provide a continuous one-year record of Working Level in the Caverns.

A typical summer visitor spending 3 hours in the Caverns receives about 0.005 WLM if a mid-range figure of 50% is used for the radon daughter equilibrium value. This is only a little more than that due to the natural (outdoor) background for the same period at about 0.002 WLM.

CONCLUSIONS

The general pattern for the level and variation of ^{222}Rn and daughter product concentrations in the Carlsbad Caverns has been presented. On the basis of limited measurements, there is general agreement between the model proposed and data obtained thus far. Continued monitoring by National Park Service personnel to obtain average seasonal values over a period of years will help establish needed modifications in the future.

Radiation exposure levels are sufficiently high, based upon these preliminary measurements, so that reasonable consideration should be given to National Park Service or other personnel working in the cave on a regular basis. The exposure received by visitors is negligible.

A continuing program of monitoring the radioactivity, temperature, humidity, airborne particulates, and air flow patterns is strongly recommended both for evaluation of the potential exposures to people entering the Caverns, and especially for providing a data base from which changing radon and daughter product concentrations can be adequately understood and predicted in the cave environment.

[3] The reader is referred to Eisenbud (1973) Chap. 3 for a comprehensive treatment of "Radiation Protection Standards" and to the following for specific references to airborne radon 222 and its daughter products: (Lawrence Berkeley Laboratory 1973), (New Mexico EIA 1973), (USEPA 1976), (US Dept. of Interior, MESA 1976) and (USNRC 1976).

LITERATURE CITED

AHLSTRAND, G. and P. L. FRY. 1976. Alpha radiation monitoring at the Carlsbad Caverns. AIBS/NPS Conference on Research in the National Parks. November 8-11, 1976, New Orleans.

CLEMENTS, W. E. and M. H. WILKENING. 1975. Atmospheric pressure effects on ^{222}Rn transport across the air-earth interface. J. Geophs. Res. 79:5025-29.

EISENBUD, M. 1973. Environmental Radioactivity. Academic Press, New York. 166-171 and 38-86.

LAWRENCE BERKELEY LABORATORY. 1973. Intrumentation for environmental monitoring, Vol. 3, Radiation, ^{222}Rn and its daughter, RAD-NUC: Radiation Protection Guides 6; Measurements of Radon 8, University of California, Berkeley.

NEW MEXICO ENVIRONMENTAL IMPROVEMENT AGENCY (NMEIA). 1973. Regulations for Governing the Health and Environmental Aspects of Radiation, June 16, 1973, Part 4, Appendix A.

TROUT, J. BOB. 1975. Radon levels and air exchange characteristics in Cottonwood and Jurnigan Caves. Master of Science Independent Study Paper (New Mexico Institute of Mining and Technology. Socorro, New Mexico).

U.S. DEPARTMENT OF INTERIOR, Mining Enforcement and Safety Administration (MESA). 1975. Radiation Survey of Carlsbad Caverns National Park. D853-R53 November 4-7, 1975. R. T. Beckham, D. D. Rapp and Lyle Rathbun; 3-6.

U.S. DEPARTMENT OF INTERIOR, Mining Enforecement and Safety Administration (MESA). 1976. Radiation Survey of Carlsbad Caverns National Park. D1118-R69 August 24-26, 1976. R. T. Beckham and D. D. Rapp: 2.

U.S. ENVIRONMENTAL PROTECTION AGENCY (EPA). 1976. Report on Ambient Outdoor Radon and Indoor Radon Progeny at Selected Locations in the Grants Mineral Belt. New Mexico ORP/LV 76-4 June 1976: 17-18.

U.S. NUCLEAR REGULATORY COMMISSION (NRC). 1976. Code of Federal Regulations, 10CFR20, Part 20 January 29, 1976.

WILKENING, M. H. 1962. Free-air exchange in an open mine tunnel determined by radon measurement. J. Geophys. Res. 67:3535 (a).

WILKENING, M. H. 1975. International Symposium on Areas of High Natural Radioactivity. Pacos de Caldas, Brazil June 1975.

WILKENING, M. H. and D. E. WATKINS. 1976. Air exchange and ^{222}Rn concentrations in the Carlsbad Caverns. Health Physics 31:139-145.

ALPHA RADIATION MONITORING AT CARLSBAD CAVERNS

Gary M. Ahlstrand and Patricia L. Fry[1]

Radon 222 is a radioactive noble gas in the natural disintegration series of ^{238}U to ^{206}Pb. The four principal radionuclides following ^{222}Rn in the series are ^{218}Po, ^{214}Pb, ^{214}Bi and ^{214}Po. The half lives of these four isotopes, sometimes referred to as short lived radon daughter products, range from 164 microseconds for ^{214}Po to 26.8 minutes for ^{214}Pb. Alpha particles are emitted during the decay of ^{222}Rn, ^{218}Po and ^{214}Po, thus, inhalation of radon and especially its daughter products can result in the delivery of alpha energy to the epithelium of the respiratory tract. Cells ionized by this radiation may die or be mutated.

A contributed study by Wilkening and Watkins (1976) reported the presence of seasonally varying levels of ^{222}Rn in Carlsbad Caverns. The study was based on four sampling periods from February 1973 to January 1975. The report implied that a health hazard might be present in the cave if radon and its daughter products were in transient equilibrium.

Subsequently, assistance from the Radiation Group of the Denver Technical Support Center, Mining Enforcement and Safety Administration (MESA) was sought to help characterize the nature of the radiation problem in the cave. Radiation surveys were conducted in November 1975 and again in August 1976 by MESA personnel at Carlsbad Caverns (unpublished reports by Beckman, Rapp, and Rathbun dated 4-7 November 1975 and Beckman and Rapp dated 24-26 August 1976 on file at Headquarters Office, Carlsbad Caverns and Guadalupe Mountains National Parks).

Ratios of radon daughter products to radon were shown in the surveys to be much lower than had been anticipated. Radon daughters are ions of heavy metals which tend to attach to available airborne condensation nuclei. In the absence of sufficient condensation nuclei, unattached daughters remain as free ions only until they can react or attach to a nearby surface. Measured concentrations of free ions were significantly higher during the August radiation survey than levels found during the November survey. Gamma radiation, and concentrations of thoron daughters (^{220}Rn daughters in the ^{232}Th radioactive disintegration series) and condensation nuclei in the cave were relatively low. Many water samples from the cave contained high concentrations of ^{226}Ra and ^{222}Rn, but due to the small quantities of water involved, these sources were considered minor contributors to the overall concentration of radon present in cave air. All solid samples analyzed demonstrated some radioactivity, but the levels were extremely low.

Arrangements were made for a limited number of employees to participate in a pulmonary cytology examination. Sputum specimens from 15 participants with employment time in the cave ranging from four to twenty-four years were sent to the laboratories of Saccomanno, Saunders, and Klein in Grand Junction, Colorado for examination of exfoliated pulmonary cells contained in the samples (Saccomanno et al. 1974). Participants included both tobacco smokers and non-smokers. Eighty percent of the participants were found to have some degree of abnormal squamous cell metaplasia evident in their samples. No conclusions concerning the reason(s) for the apparently high incidence of abnormal cells can be stated on the basis of the initial study due to the limited sample size, sampling methods and the absence of a suitable control group. The study did suggest the need for a more thorough follow-up study which was recently initiated at Carlsbad Caverns by personnel from the National Institute for Occupational Safety and Health (NIOSH). A complete summary of the NIOSH study is not yet available, but indications are that atypical cells are again common among the participants. Comparison of data from participants at other National Park Service (NPS) administered caves and with appropriate controls are still to be made.

Predictions based on a model by Wilkening and Watkins (1976) and on annual variations in carbon dioxide concentrations in Carlsbad Caverns (McLean 1971) indicated that annual internal alpha exposure limits set for uranium miners might be exceeded by some employees in the cave. A radiation monitoring program using exposure standards for miners as guidelines was initiated at the park on 1 September 1975. Data from the first year's study are presented in this paper.

METHODS

Underground portions of Carlsbad Caverns National Park regularly frequented by visitors and staffed with NPS employees are monitored on a regular basis to determine the levels of radon daughter products present. Four work areas or occupational zones have been designated in Carlsbad Caverns: the Main Corridor, the Scenic Rooms, the Big Room, and the Lunch/Pump Room area. Each occupational zone is monitored by drawing a known volume of air through a fiberglass filter. Consecutive five minute walking samples are obtained along an established route through each occupational zone. Ten walking samples are required to monitor the four occupational zones. Alpha activity from radon daughters trapped on the filter is detected at a measured time after sampling with a scintillation counter. Details for the procedure, termed the Kusnetz method are discussed by Budnitz (1974).

The term used to describe atmospheric concentrations of radon daughters is the working level (wl), often described as the latent alpha energy inherent in a liter of air containing 100 pCi each of ^{218}Po, ^{214}Pb, ^{214}Bi and ^{214}Po. A more precise definition for the working level is any combination of radon daughters in one liter of air that will ultimately release 1.3×10^5 MeV of alpha energy during decay to ^{210}Pb. During the first year of the program, Carlsbad Caverns was monitored at least weekly when mean radon concentrations were 0.20 wl or less and twice weekly when the mean was greater than 0.20 wl.

Radon levels have been measured continuously in the Pump Room of Carlsbad Caverns since May 1976 with a radon monitoring system on loan from the Denver Mining Research Center, U. S. Bureau of Mines. The system consists of a scintillation

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type detector, and controlled airflow and data acquisition systems. Radon is measured by drawing an air sample continuously through a filter and the detector at a constant flow rate. Alpha particles resulting from the decay of radon and its daughter products produce pulses which are amplified, counted, and logged by the data acquisition system.

Atmospheric pressure is monitored in the Pump Room of the cave with a recording barograph. Daily temperature extremes are obtained from a maximum-minimum thermometer placed in a weather instrument shelter located approximately 150 meters from the natural entrance to the cave.

Individuals employed in the cave are required to maintain daily records of time spent in each occupational zone. Exposures are calculated in working level months (wlm) from individual time records and the weekly mean radon daughter concentration for each occupational zone. A working level month is the exposure received by breathing air at one working level concentration for four and one-third weeks of 40 hours each. Federal standards for miners state that cumulative individual exposures shall not exceed four working levels in any calendar year.

RESULTS AND DISCUSSION

Data from the first year of monitoring radon daughter products in Carlsbad Caverns are summarized in Figure 1. The levels vary seasonally and follow the same general curve formed by a plot of daily minimum temperatures for about 15°C and below.

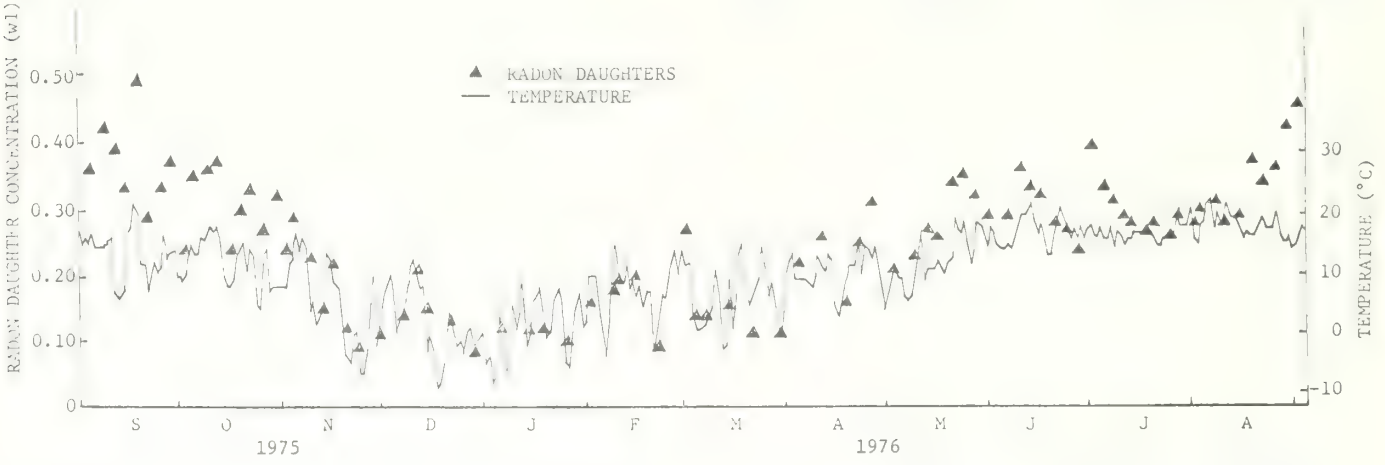

FIGURE 1. Comparison of seasonal fluctuation of average radon daughter concentrations in visited portions of Carlsbad Caverns with daily minimum temperatures at the park. Each radon daughter concentration is the mean of ten samples required to monitor the four occupational zones.

Temperatures within the cave vary from about 11°C to over 19°C, but are relatively constant throughout the year for any given portion of the cave. Practically all parts of the cave lie below the known entrances. Most of the exchange between cave and outside air takes place through these known entrances which open to areas of the cave maintained at about 11-15°C. As daily outside minimum temperatures remain above approximately 15°C, the overlying less dense air lends stability to the cave air. Apparently some air exchange occurs between cave and outside air through not yet discovered openings at lower and warmer levels of the cave until the overlying air temperature remains above the maximum cave air temperature.

The slowed rate of air exchange during the summer months accounts for the higher radon and daughter product concentrations measured in the cave during this time of the year. Transient equilibrium between radon and its daughters can be established in about three hours under stable conditions. As overlying air temperatures drop below the cave minimum temperature, air density differentials result in lower radon daughter product levels due to hastened cave air turnover rates and diluted radon concentrations.

Radon levels in the cave often show marked daily fluctuations in addition to large scale seasonal variations. These shorter term radon fluctuations are related to atmospheric pressure and temperature changes (Figure 2). Low pressure systems attaining minimum values on 14 August, 12 September and 26 September were accompanied by elevated radon concentrations. More evident were the high pressure systems of 29 August and 9 September that were accompanied by decreased radon emanation.

The combined effects of a high pressure system with the depression of outside temperatures below cave air temperatures leads to a pronounced reduction in the radon concentration as evidenced on 28-30 September, 7 October and 16 October (Figure 2).

Maximum radon daughter product concentrations measured during 1976 were monitored on 3 September (Figure 1). Prior to and on that date the daughter products were approaching equilibrium with radon (Figure 2).

Ranges of radon daughter concentrations for the four occupational zones throughout the year were: Main Corridor, 0.06-0.45 wl; Scenic Rooms, 0.08-0.55 wl; Big Room, 0.10-0.53 wl; and Lunch/Pump Room, 0.07-0.51 wl. The highest concentration measured thus far was 1.13 wl in a portion of Lower Cave, a non-developed area of Carlsbad Caverns.

Relative radon daughter levels for the occupational zones were lowest in the Main Corridor area from mid-September through mid-May, but were often the highest of any occupational zone during July and August. All known natural openings are adjacent to the Main Corridor area and the relative values are consistent with observed ventilation patterns related to differential air densities. The Big Room, most distant area regularly monitored from a known natural opening, consistently has the highest daughter product levels throughout the year.

The greatest cumulative exposure acquired by

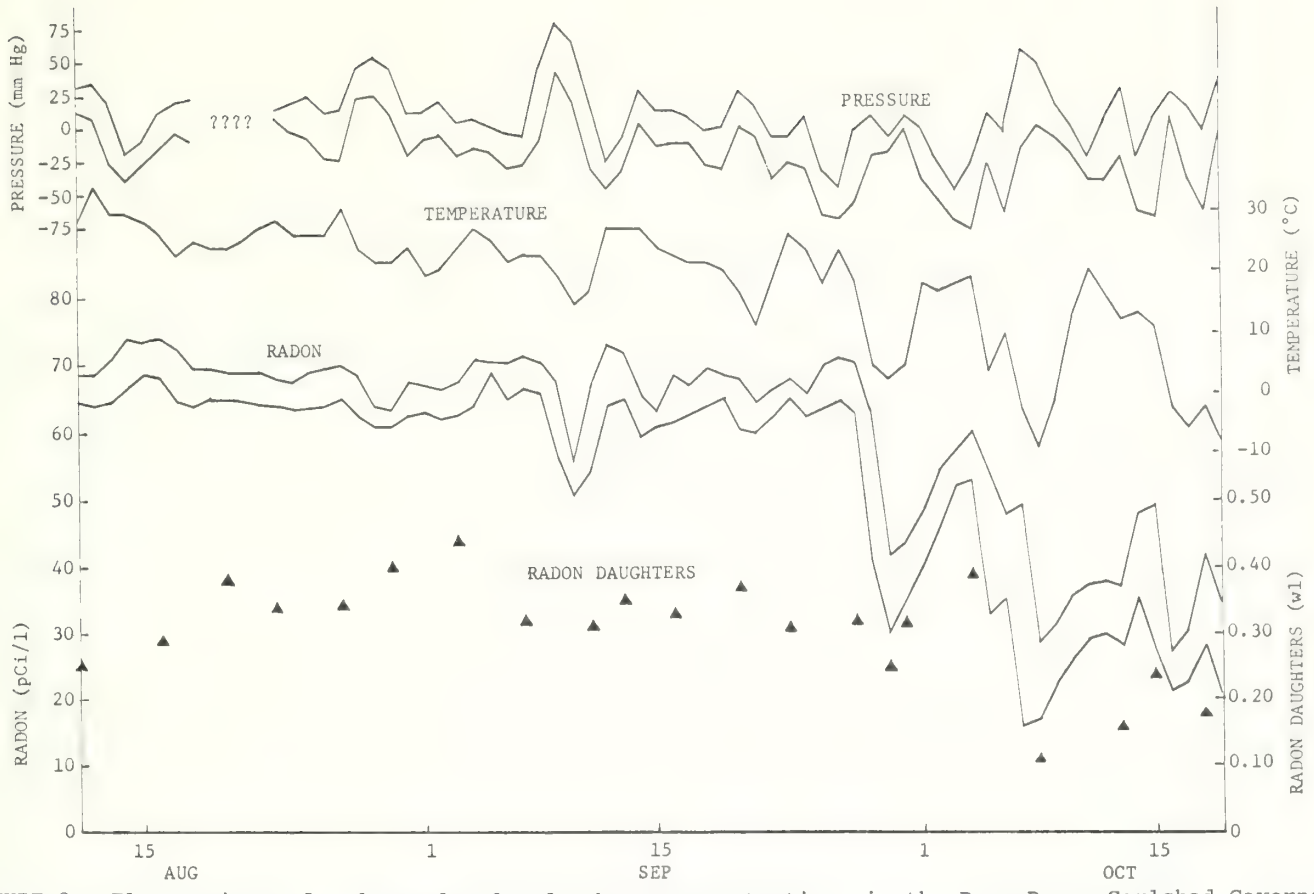

FIGURE 2. Fluctuations of radon and radon daughter concentrations in the Pump Room, Carlsbad Caverns in response to pressure and temperature changes. Radon and pressure data are daily maximum and minimum values. Temperature is the daily minimum.

any employee at Carlsbad Caverns during the first 12 months of the monitoring program was 2.70 wlm, well below the maximum set for miners. Individual exposures are at best estimates, due to recognized inaccuracies in the monitoring methods employed, and may be in error by 50 percent or more. The standards set for miners are subject to these same inaccuracies since they are based on individual exposure estimates from epidemiological studies of uranium miners.

The degree of health hazard associated with a given cumulative exposure is further complicated by the working level month being an alpha radiation *exposure rate*, while the alpha radiation *absorbed dose* received by critical tissue areas constitutes the actual health hazard. Additional work is needed to better define the relationship between alpha exposure and absorbed radiation dose.

Mention should be made of the apparent increased health hazard imposed on the individual that combines the smoking habit with exposure to radon daughter products. Archer et al. (1973) in a study involving more than 4100 uranium miners reported that the incidence of lung cancer among cigarette smokers exposed to alpha radiation to be approximately ten times as great as expected. In a study involving sputum samples from more than 5500 individuals, Saccomanno et al. (1974) concluded that tobacco smokers in the group, both miners and non-miners, had a much greater incidence of atypical epithelial cells from the respiratory tract than did non-smokers. Martell (1975) has suggested that radionuclides concentrated in insoluble tobacco smoke particles may account for the much higher incidence of lung cancer in smokers. In contrast, radionuclides inhaled on most condensation nuclei are soluble in lung fluid and are readily cleared from the lung.

The monitoring program and related radiation research at Carlsbad Caverns has provided many needed answers. However, the information gained from the monitoring program is of limited value unless its significance can be adequately explained to those employees involved. Studies should be initiated to better define the actual health hazard to these employees by inhalation of radon daughter products in caves. Information from the pulmonary cytology study now being conducted by NIOSH personnel should give impetus and direction to this problem.

REFERENCES

ARCHER, V. E., J. K. WAGONER, and F. E. LUNDIN. 1973. Lung cancer among uranium miners in the United States. Health Physics 25:351-371.

BUDNITZ, R. J. 1974. Radon-222 and its daughters--a review of instrumentation for occupational and environmental monitoring. Health Physics 26:145-163.

MARTELL, E. A. 1975. Tobacco radioactivity and cancer in smokers. American Scientist 63: 404-412.

MCLEAN, J. S. 1971. The Microclimate in Carlsbad Caverns, New Mexico. Open-file report, U. S. Geological Survey, 67p.

SACCOMANNO, G., V. E. ARCHER, O. AUERBACH. R. P. SAUNDERS, and L. M. BRENNAN. 1974. Development of carcinoma of the lung as reflected in exfoliated cells. Cancer 33:256-270.

WILKENING, M. H. and D. E. WATKINS. 1976. Air exchange and ^{222}Rn concentrations in the Carlsbad Caverns. Health Physics 31:139-145.

THE INFLUENCE OF PRESCRIBED FIRES ON WATER-REPELLENCY OF MIXED-CONIFER FOREST FLOOR

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INTRODUCTION

Fire has played a natural role in the evolution of most national park ecosystems. The presence of fire in past centuries in western forests is well established (Show and Kotok 1924; Weaver 1951), and surface fires were common in the mixed-conifor forests of California. However, when American parks were first set aside in the late nineteenth century, they became selectively protected against many natural processes, including fire. After 60 to 80 years of a fire exclusion policy, fires are now being introduced to national park ecosystems (Agee 1974). Although natural fires are the preferred means to meet fire management objectives, prescribed fires may be used in ecosystems significantly modified by the prolonged exclusion of fire.

The fire exclusion policy in mixed-conifer forests allowed unnaturally dense vegetation and high fuel loads to develop, and altered the hydrologic properties of forest floors. Ground fuels intercepted considerably larger amounts of water, yet provided more detention storage for storm precipitation that might otherwise become overland flow. In the process of reintroducing fire, changes in the physical and hydrologic properties of the forest floor are expected. This paper reports prescribed fire effects on water-repellency of mixed-conifer litter, duff, and surface soil.

Non-wettable soils naturally occur around the world. Such soils, when dry, do not readily absorb water due to organic compounds coating soil particles. Leachates from resinous leaves and fungi are known to contain hydrophobic substances, and aliphatic hydrocarbons in leaves have been shown to be an important source of water-repellent compounds (Save et al. 1972). These substances leach into the soil over time where they coat soil particles and increase apparent liquid-solid contact angles (DeBano 1966).

Water-repellency can be intensified by burning, which volatizes and perhaps polymerizes hydrophobic compounds and allows them to diffuse into the soil, where a decreasing temperature gradient results in their condensation on soil particles. In a low or medium intensity fire, the hydrophobic layer may be restricted to the soil surface, whereas in high intensity fires the layer may be many centimeters below the surface, due to deeper distillation of the hydrophobic compounds and the destruction of surface water-repellency by intense heat (DeBano et al. 1967). Water-repellency is most pronounced in coarse-textured soils with low specific surfaces, because the hydrophobic substances can more completely coat the smaller particle surface area of sandy soils (DeBano et al. 1970). Most water-repellency work has been done in chaparral ecosystems.

METHODS

The study area was located adjacent to Kings Canyon National Park, California (Figure 1). The research design used was a three-way nested factorial using as independent variables ponderosa pine-incense cedar (pine-cedar) and white fir-giant sequoia (fir-sequoia) overstory communities, dense and open understory types nested within each community, and two levels of fire intensity, using as an index 10-hour timelag fuel moistures of 13 and 10 percent (measured by fuel moisture sticks) in early to mid-spring.

Twelve 10 X 10 m plots, each surrounded by a 5 m buffer zone, were established. Each large plot had 20 paired subplots, which individually measured 20 X 50 cm (0.1 sq m); 10 were measured before burning and the remaining 10 paired subplots were measured after burning. The sample size was adequate to measure several parameters within at least 10 percent of the mean at $\alpha = .05$ and $\beta = .10$.

Field sampling consisted of measuring field characteristics or collecting laboratory samples on the 0.1 sq m subplots. Water retention was measured using a modified model of the Adams et al. (1957) and McQueen (1963) rainfall-simulator infiltrometers at a rate of 10.16 cm/hr (4 in/hr) for 30 minutes; runoff and sediment were collected on each plot. Litter samples (fresh and slightly weathered material), duff samples (highly weathered or decomposed material) and Shaver sandy loam surface soil (to 5 cm depth) were collected on each "before" paired subplot. When weather conditions, as measured by 10-hour timelag moisture content, were ideal for a given plot, a backing fire was set and burned over the plot. The time-temperature data were collected using pyrometers with thermocouples placed at the litter surface, duff surface, soil surface, and at 5 cm soil depth. Post-fire field sampling duplicated pre-fire sampling techniques.

Laboratory analyses were conducted on litter, duff, and soil samples to determine initial wettability and changes due to burning. A wettability index for litter and duff samples was made by measuring water drop penetration time into a filter paper containing a dried extract of plant material, similar to the technique of DeBano (1969b). The extract was prepared by adding 40 ml of 0.1N ammonium hydroxide (NH_4OH) to 5 g of litter or duff which had been ground in a 20 mesh Wiley mill, and shaking the mixture for one minute. The mixture was filtered through a Buchner funnel and a Whatman no. 42 filter paper was then immersed in the filtered solution. Upon removal it was dried and placed in a desiccator for 48 hours, at which time it was subjected to the water drop test. A series of ammonium hydroxide blanks were concurrently run.

The wettability of soil was tested in two ways: measurement of the apparent liquid-solid contact angle (Letey et al. 1962) and water drop penetration time (Bond and Harris 1964). Water drop penetration time was measured by placing a drop of distilled water on a soil sample that had been dried in a desiccator for 48 hours, so that samples had approximately the same matric suction at the time the water drop was applied.

Measurement of liquid-solid contact angles has come under criticism for several reasons. The technique does not measure an actual angle, but an apparent one that is also dependent on pore size. Where pore channels converge and diverge

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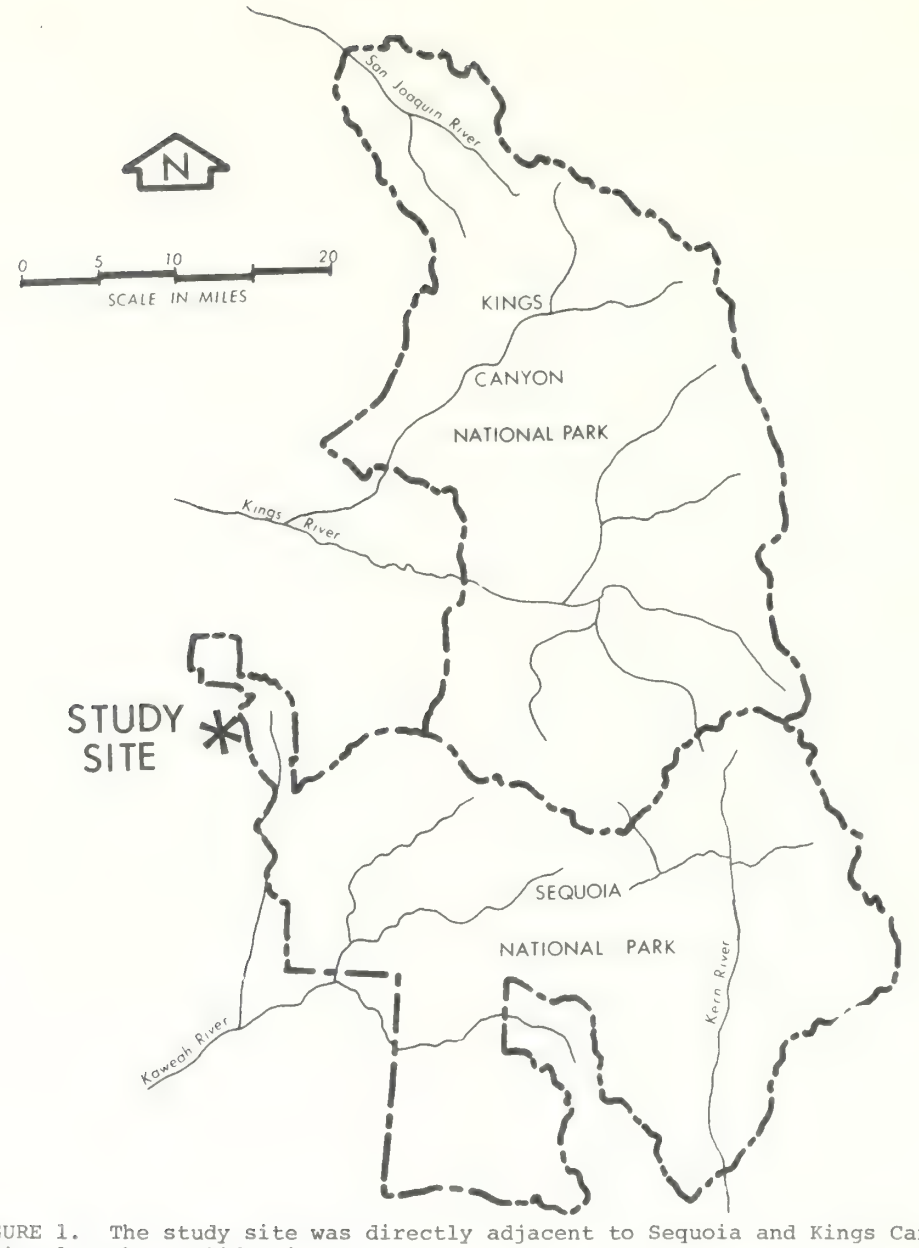


FIGURE 1. The study site was directly adjacent to Sequoia and Kings Canyon National Parks, California.

FIGURE 2. Fires in pine-cedar communities evenly burned over the plots.

FIGURE 3. Fires in fir-sequoia communities progressed primarily by smoldering, and fire spread was erratic.

TABLE 1. Statistical eignificance of analyses. NS = non-significant; * = significant at $\alpha = 0.05$, $\beta = 0.10$.

Independent variables	Dependent variables: Litter-duff WDPT Before	Litter-duff WDPT Burn effect	Soil WDPT Before	Soil WDPT Burn effect	Soil CRI Before	Soil CRI Burn effect
Main effects						
Overstory community (OC)	*	NS	NS	NS	NS	*
Understory density (UD)	NS	NS	NS	NS	NS	NS
Forest floor layer (FFL)	*	*				
Fuel moisture (FM)		*		NS		NS
Interactions						
FM-OC		*		NS		NS
FM-UD		*		NS		NS
FM-FFL		*				
Covariate						
Percent moisture					*	*

a unique relation between relative sorptivity and contact angle does not exist (Phillip 1971, Bond and Hammond 1970). The apparent angle is thus a function of the true angle and the geometry of the medium, a concept forwarded 30 years ago in the English textile industry (Cassie and Baxter 1944, 1945). A second disadvantage is that this method is not an equilibrium measurement as the derivation of the theory assumes. The height of capillary rise method is a useful water-repellency index, and calling it something other than a liquid-solid contact angle would negate the need for equilibrium conditions, and differentiating between an advancing and receding angle. In this study, the original technique was used, but the calculated result is instead called the capillary rise index.

Analysis of variance and analysis of covariance models were used to determine main, interaction, and covariate effects on the dependent wettability variables.

Pre-fire capillary rise and water drop penetration time data were analyzed using a two-way nested analysis of variance model:

$$Y_{ijk} = \mu + \alpha_i + \beta_{j(i)} + \varepsilon_{ijk}$$

where Y_{ijk} represents the dependent variable, μ is the population mean, α_i is overstory community, $\beta_{j(i)}$ is understory density, statistically nested within overstory community because of the absence of randomization in assigning a stationary understory density, and ε_{ijk} is the error term.

For initial litter and duff wettability, a two-stage nested model was necessary in order to compare the two forest floor layers (litter and duff). In this model, forest floor layer is nested with understory density which itself is nested within overstory community. The pre-fire model is:

$$Y_{ijkm} = \mu + \alpha_i + \beta_{j(i)} + \theta_{k(ij)} + \varepsilon_{m(ijk)}$$

where $\theta_{k(ij)}$ is the layer effect and the other terms are the same in the other pre-fire model.

Post-fire analysis utilized a number of models, differing in the number of two-way interactions present or the presence of covariates. The dependent variables used were differences between before-after samples.

Differences in soil water drop penetration time were analyzed using the model:

$$Y_{imkm} = \mu + \alpha_i + \beta_{j(i)} + \gamma_k + \gamma\alpha_{ik} + \gamma\beta_{jk(i)} + \varepsilon_{ijkm}$$

where α_i is overstory, $\beta_{j(i)}$ is understory density, γ_k is fuel moisture, $\gamma\alpha_{ik}$ is fuel moisture-overstory community interaction, $\gamma\beta_{jk(i)}$ is understory density-fuel moisture interaction, and ε_{ijkm} is the error term. Because of the nested design, the two-way interaction between overstory community and understory density is missing and the three-way interaction is also nonexistent.

Differences in capillary rise index were analyzed using a three-way nested analysis of covariance model:

$$Y_{ijkm} = \mu + \alpha_i + \beta_{j(i)} + \gamma_k + \gamma\alpha_{ik} + \gamma\beta_{jk(i)} + \delta S_{ijkm} + \varepsilon_{ijkm}$$

where the additional term is a covariate δ, air dry moisture content. This term was included to increase the sensitivity of the model by removing the effect of moisture before the treatment effects are determined.

Differences in litter and duff wettability were analyzed using a four-way, doubly nested analysis of variance model:

$$Y_{ijkmn} = \mu + \alpha_i + \beta_{j(i)} + \gamma_k + \theta_{m(ij)} + \gamma\alpha_{ik} + \gamma\beta_{jk(i)} + \gamma\theta_{km(ij)} + \varepsilon_{ijkmn}$$

where $\theta_{m(ij)}$ is the layer effect, $\gamma\theta_{km(ij)}$ is the layer-fuel moisture interaction, and the other terms are as previously defined.

RESULTS

The wettability analyses showed that statistically significant water-repellency naturally occurs in mixed-conifer forest floors, and is altered by burning. The results are summarized in four categories: *fire characteristics, litter and duff wettability, soil wettability,* and *the relation between forest floor wettability and water retention.* The statistical significance of the analyses is summarized in Table 1.

Fire Characteristics

Fire intensities on the plots ranged from 12.6 to 77.2 Kcal/m/sec. Fire intensity was greater on plots burned at 10-hour timelag moisture contents of 10 percent than those burned at 13 percent. Under moist conditions, dense understories reduced fire intensities, while at drier fuel moistures, dense understories helped to increase fire intensity because the understory became available fuel. All fires in pine-cedar communities burned fairly evenly over the plots, aided by the loose, aerated pine needle ground cover (Figure 2). In fir-sequoia communities, fire spread was erratic and progressed primarily by smoldering; intensity was difficult or impossible to measure on these plots (Figure 3).

Time-temperature data were collected on each plot during the fire pass. Moisture in the forest floor had a large effect on heat penetration into the soil, illustrated by Plot 22 (pine-cedar, dense understory, burned at 10 percent fuel stick moisture).

As shown in Figure 4, the fire passed over the thermocouples within 30 minutes, but smoldering continued in the duff for two hours, maintaining a temperature of 100 degrees C while moisture vaporized. At the three-hour mark, the duff finally caught fire, and duff temperatures increased to over 150 degrees C, but within 30 minutes began to diminish again.

Litter and Duff Wettability

Litter and duff samples in both the pine-cedar and fir-sequoia communities exhibited significant water-repellency, which was altered by burning. The water drop penetration tests into filter paper before burning showed two significant differences (Figure 5): pine-cedar samples are more repellent than fir-sequoia samples, and litter water-repellency exceeded that of the duff for the dense understory pine-cedar community. This was the only significant litter-duff contrast although for all plots the average water repellency of litter exceeded duff water-repellency.

Changes in water drop penetration time after burning (Table 2) were analyzed and showed five significant effects: fuel moisture level, forest floor layer, and three interactions: fuel moisture-layer, fuel moisture-understory density, and fuel moisture-overstory community. The presence of three significant interactions makes visual interpretation of the data very difficult. Apparently, fires burning under moist conditions increased water-repellency in the residual fuels, while the more intense fires volatized repellent compounds in residual fuels and made them less water-repellent. For the pine-cedar plots, burning under the moist conditions increased the water drop penetration time of the litter more than the duff, but both increased. Burning under the drier conditions decreased both litter and duff water drop penetration times, and the litter became more wettable than the duff. The fir-sequoia results were less clear and due partly to

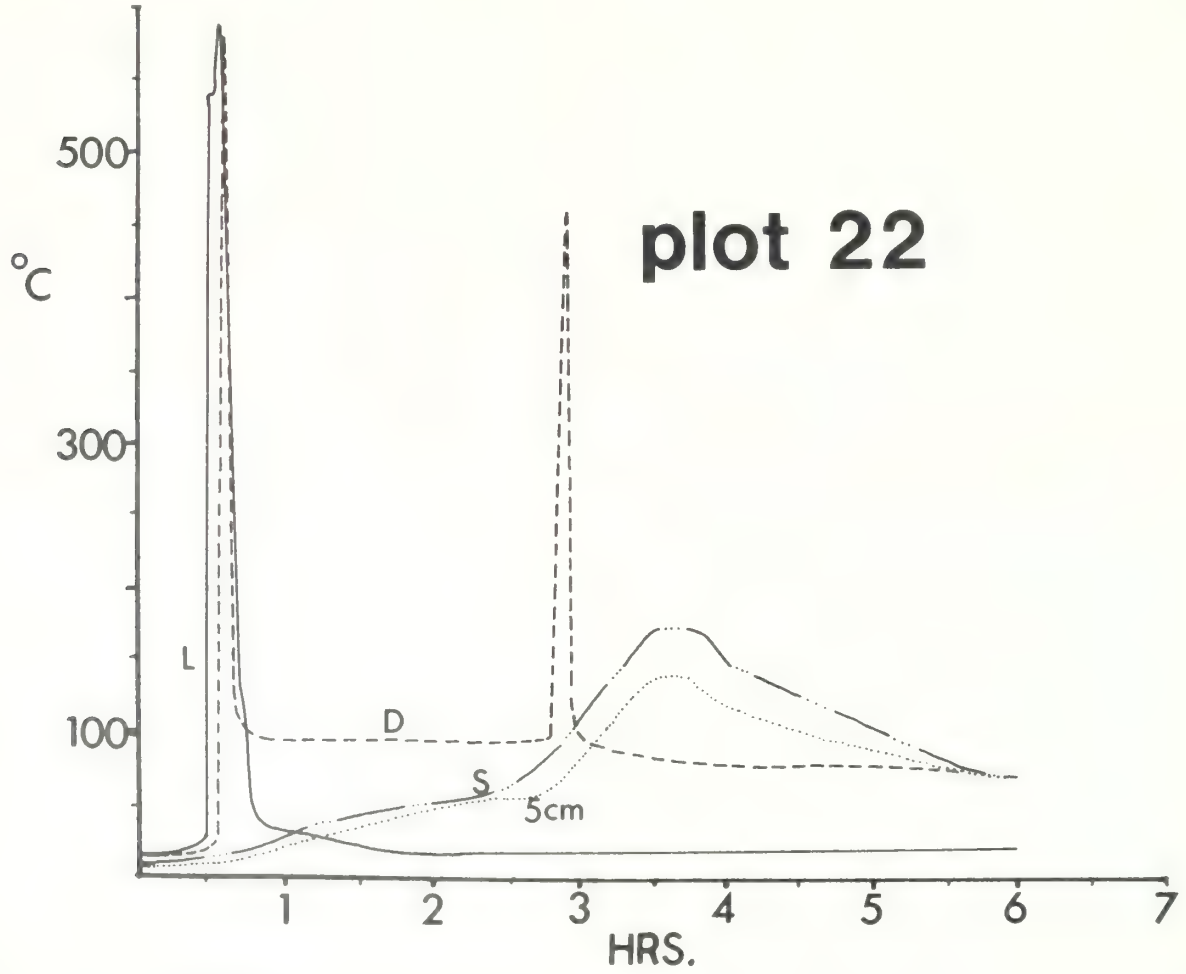


FIGURE 4. A time-temperature profile on a pine-cedar plot. L = litter surface, D = duff surface, S = soil surface, and 5cm = 5cm soil depth.

the patchy fire coverage on those plots under the research burning conditions.

Extrapolation of these filter paper results to the field can only be done in a general sense, for under field conditions samples are not ground up nor are they treated with ammonium hydroxide. It appears that light burning can concentrate non-wettable compounds on the residual fuels, and that more intense burning removes these compounds and makes the residual fuel more wettable. However, these results apply to fuel *particles* only, and water absorption by the forest floor depends largely on the matrix created by the arrangement of fuel particles.

Soil Wettability

The potential water repellency of all soil samples was tested in two ways: the short-term water drop penetration time, and the longer term capillary rise index.

Before burning, samples on all subplots were tested by both methods, with no significant main effects (Table 3). The initial water drop penetration times averaged 17½ minutes, with no significant differences between plots. The water drops tended to ball up on the soil surface and infiltrate very slowly, and there were large within-plot variances. The capillary rise index tests had more uniform results, with before burning averages clustered around 75 degrees, and a range of 63-89 degrees. Initial soil moisture content was a significant covariate, but there were no other significant effects before burning.

As with litter and duff wettability, differences in soil wettability due to burning were analyzed. There were no significant differences in water drop penetration time. Within-plot variation remained high and accounted for over 90 percent of the total variance.

The capillary rise index analysis of before-after differences showed two significant effects: overstory community and the covariate average soil moisture content. Post-fire samples in pine-cedar plots, including control plots, increased an average of 0.72 degrees, or about 1 percent, with slightly higher though nonsignificant increases on the plots burned under the drier conditions. Had soil layers thinner than 5 cm been considered, as difficult as it would have been to separate such layers in the hummocky soil microrelief, soil wettability effects might have been more statistically significant.

Forest Floor Wettability and Water Retention

The relation between wettability and water retention was investigated using linear regression models. Water retention was the dependent variable, and a host of independent variables were used. The number of independent variables ranged from one to seven and included combinations of total fuel weight, subplot slope, litter water drop penetration time, percent soil carbon, soil bulk density, percent soil moisture, percent soil less than 2 mm, and capillary rise index. Obviously correlated variables like soil bulk density and percent soil carbon were not included in the same equation. None of the equations explained more than 40 percent of the total variance of water retention. However, total fuel weight accounted for about 50 percent of the maximum explained variance, and subplot slope, percent soil moisture, percent soil less than 2 mm, and capillary rise index had coefficients significantly greater than zero and each helped to explain a few percent of the total variance.

Total fuel weight was most highly related to water retention because of the capacity of the fuel matrix for holding water and the type of precipitation applied. A simulated thunderstorm-type rainfall intensity was used in the study, and detention storage by the forest floor was important.

Soil wettability was significantly related to water retention, but litter wettability was not. Although many statistically significant changes occurred in litter and duff wettability, water retention was not significantly affected by these changes. Variation in soil capillary rise index did affect water retention, though.

DISCUSSION

Water-repellency naturally occurs in mixed-conifer forest floors. Dyrness (1976) proposed that liquid-solid contact angles (capillary rise indexes) between 70 and 80 degress in soil indicated at least moderate resistance to wetting, which correspond to the soil data in this study. Litter and duff layers also exhibited natural water-repellency, and the litter in pine-cedar plots appeared to be most repellent. The source of the hydrophobic properties may be constituents of needles, fungal mycelia, or a combination of both. Some of the most water-repellent individual samples were pine needle samples relatively free of visually apparent fungal mycelia, and soil samples under fir-sequoia litter and duff which were penetrated by a network of white mycelia.

The results of this study do not conclusively establish the effect of fire on forest floor wettability. Though the temperature data show most

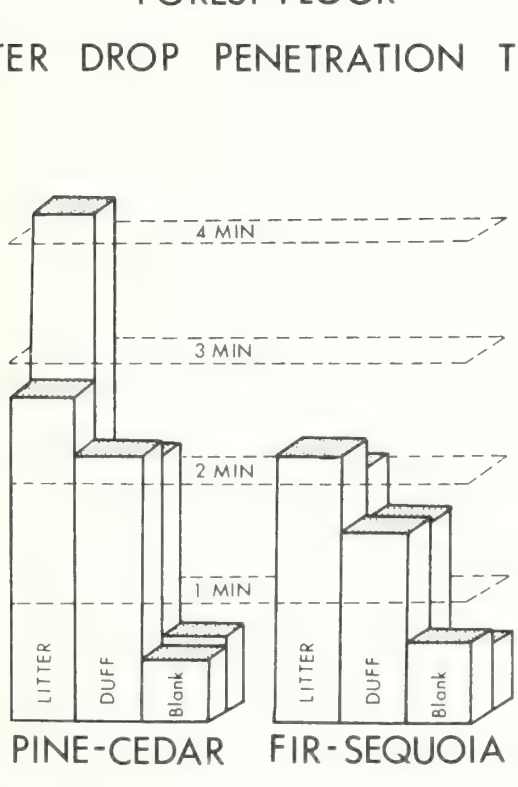


FIGURE 5. Water drop penetration time into filter paper containing dried extract of plant material. Foreground columns are open understory plots; backgriund columns are dense understory plots.

of the soil surface temperatures reaching 100-200° C, the minimum temperature to intensify natural nonwettability (DeBano 1966; Cory and Morris 1969), there was little temperature rise at 5 cm soil depth. Since the most water-repellent organic fraction volatizes above 300° C (Savage et al. 1972), condensation of water-repellent compounds was probably confined to the lower residual duff layer and surface of the soil due to a rapidly declining temperature gradient. The forest floor wettability results confirm that the duff became less wettable after light burning, but the use of a relatively thick 5 cm soil slice for soil wettability tests might have masked some soil repellency effects. Given the methods of this study, soil water repellency was not affected by burning as much as was litter and duff wettability.

TABEL 2. Differences in water drop penetration time (WDPT), seconds. Values are before minus after, so that a negative value means increased water repellency.

Independent / Dependent	Pine-Cedar				Fir-Sequoia			
	Open		Dense		Open		Dense	
	Litter	Duff	Litter	Duff	Litter	Duff	Litter	Duff
Burn-13% Fuel Moisture	-32.8	-13.9	-300.3	-132.6	68.3	32.5	32.2	33.1
Burn-10% Fuel Moisture	99.9	67.9	98.1	56.9	-10.8	-15.0	54.4	18.3

TABLE 3. Water drop penetration time)seconds) and capillary rise index (degrees) before burning.

Independent / Dependent	Pine-Cedar		Fir-Sequoia	
	Open	Dense	Open	Dense
WDPT	983.4	454.4	1574.8	1158.7
Capillary Rise Index	75.99	76.02	76.25	75.33

A hypothesis explaining the low intensity fire-wettability relation in pine-cedar forest floors has generated using the data in this study and similar studies (Figure 6). DeBano et al. (1967) have established the hypothesis that natural water repellency in chaparral ecosystems can be shifted downward into the soil due to distillation of water-repellent compounds and subsequent condensation in deeper soil layers where temperatures are cooler. Dyrness (1967) presents data for water-repellency in Oregon lodgepole pine stands after a wildfire that are consistent with the chaparral hypothesis.

Natural water repellency exists in mixed-conifer litter, duff, and soil. When surface or understory fires pass over an area, water-repellent compounds are volatilized. Some pass into the air; others distill downward through the litter, duff, and soil, with the ultimate effect dependent on heat penetration and temperature increases through these layers. Temperature increases can be very generally predicted by the intensity of the fire. Where intensities are less than 25 Kcal/m/sec, there are quite often substantial residual amounts of litter and duff, which appear to function as an adsorption matrix for the water-repellent compounds. In fires with intensities from 25 to 100 Kcal/m/sec, much less residual fuel is present, much of it is charred, and it may be more wettable than in the unburned state. Soil water repellency begins to increase.

In very intense fires, the litter and duff layers may be totally consumed, and the surface soil may be wettable, underlain by a variable-width water-repellent soil layer, similar to what others have found after intense fires in chaparral and forest ecosystems.

Low intensity prescribed fires, while causing statistically significant hydrologic impacts on mixed-conifer forest floor, appear to have little impact on watershed runoff and erosion. The overstory tree canopy is usually not affected, and water infiltration rates remain high. Visual inspection of many low intensity prescribed fire sites have uncovered no evidence of significant accelerations of concentrated surface runoff, surface erosion, or mass movement due to burning. The small changes in forest floor wettability due to burning are more statistically significant than practically significant. Low intensity prescribed fires appear to influence other ecosystem characteristics, such as vegetation structure and pattern, more than selected hydrologic properties of mixed-conifer ecosystems.

LITERATURE CITED

ADAMS, J. E., D. KIRKHAM, and D. R. NIELSON. 1957. A portable rainfall-simulator infiltrometer and physical measurements of soil in place. Soil Sci. Soc. Amer. Proc. 21:473-477.

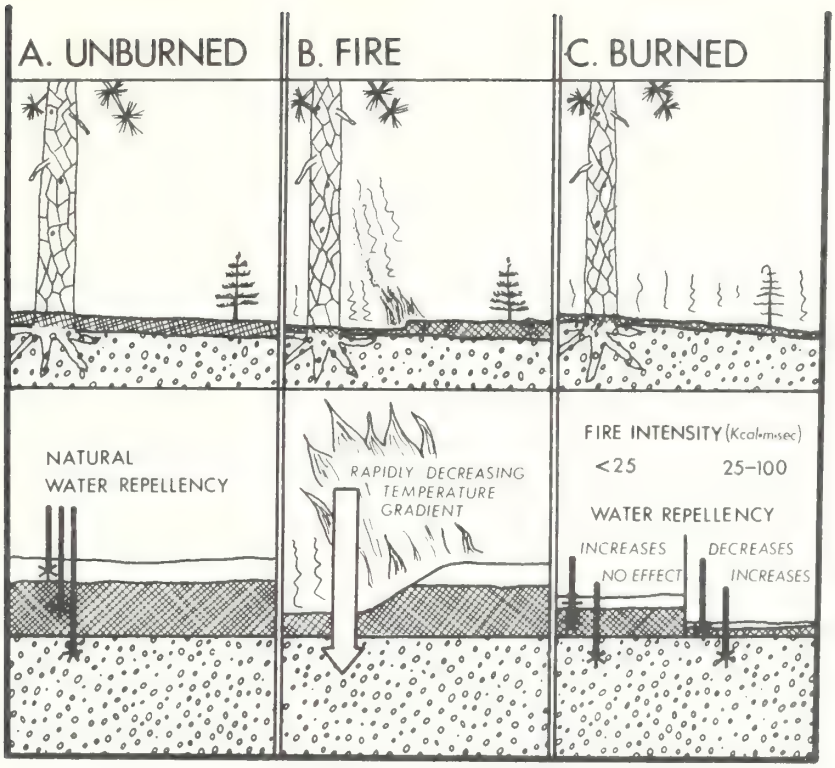
AGEE, J. K. 1974. Fire management in the national parks. Western Wildlands 1 (3):27-33.

BOND, R. D., and J. R. HARRIS. 1964. The influence of the microflora on the physical properties of soils. 1. Effects associated with filamentous fungi and algae. Aust. Jour. Soil Res. 2:111-122.

BOND, R. D. and L. C. HAMMOND. 1970. Effects of surface roughness and pore shape on water repellence of sandy soils. Soil and Crop Sci. Soc. Fla. Proc. 30:308-315.

CASSIE, A. B. D., and S. BAXTER. 1944. Wettability of porous surfaces. Trans. For. Sco. 40:546-551.

_____. 1945. Large contact angles of plant and animal surfaces. Nature 155:21-22.



CORY, J. T., and R. J. MORRIS. 1969. Factors restricting infiltration rates on decomposed granitic soils. In DeBano, L. F. and J. Letey, eds., Water-repellent soils. Proc. Symp. University of California, Riverside, pp. 149-162.

DEBANO, LEONARD F. 1966. Formation of non-wettable soils...involves heat transfer mechanism. U.S.D.A. Forest Service Res. Note PSW-132. Pacific Southwest Forest and Range Expt. Sta., Berkeley, California. 8 p.

_____. 1969-a. Water movement in water-repellent soils. In DeBano, L. F. and J. Letey, eds., Water-repellent soils. Proc. Symp. University of California, Riverside, pp. 61-90.

_____. 1969-b. The relationship between heat treatment and water repellency in soils. In DeBano, L. F. and J. Letey, eds., Water-repellent soils. Proc. Symp. University of California, Riverside, pp. 265-279.

_____. JOSEPH F. OSBORN, JAY S. KRAMMES, and JOHN LETEY, JR. 1967. Soil wettability and wetting agents...our current knowledge of the problem. U.S.D.A. Forest Service Res. Paper PSW-43. Pacific Southwest Forest and Range Expt. Sta., Berkeley, California. 13 p.

_____. L. D. MANN, and D. A. HAMILTON. 1970. Translocation of hydrophobic substances into soil by burning organic matter. Soil Sci. Soc. Amer. Proc. 34(1):130-133.

DYRNESS, C. T. 1976. Effect of wildfire on soil wettability in the High Cascades of Oregon. U.S.D.A. Forest Service Res. Paper PNW-202, Pac. NW For. and Range Expt. Sta., Portland, Oregon 18 p.

LETEY, J., J OSBORN, and R. E. PELISHEK. 1962. Measurement of liquid-soil contact angle in soil and sand. Soil Sc. 93:149-153.

MCQUEEN, I. S. 1963. Development of a hand portable rainfall-simulator infiltrometer. U.S.D.I. Geol. Survey Circular 482, Washington, D.C. 16 p.

PHILLIP, J. R. 1971. Limitations on scaling by contact angle. Soil Sci. Soc. Amer. Proc. 35:507-509.

SAVAGE, S. M., J. OSBORN, J. LETEY, and C HEATON. 1972. Substances contributing to fire-induced water-repellency in soils. Soil Sci. Soc. Amer. Proc. 36:674-678.

SHOW, S. B., and E. I. KOTOK. 1924. The role of fire in the California pine forest. U.S.D.A. Bull. 1294, Washington, D. C. 80 p.

WEAVER, HAROLD. 1951. Fire as an ecological factor in the southwestern ponderosa pine forest. Jour. For. 49:93-98.

INVESTIGATION OF RADIATION PRODUCED BY RADON AND THORON IN NATURAL CAVES ADMINISTERED BY THE NATIONAL PARK SERVICE

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There are many hazards involved in entering caves. This applies to both the casual visitor who takes an occasional guided tour along a paved path in a "developed" cave as well as to the sport caver or ardent speleologist who enters "wild" caves to explore and map, to sightsee, or to conduct scientific research. Among these hazards are rock falls; slips and falls while moving around in the cave; high CO_2 and resulting O_2 deficient air; deep water pools and flowing streams; the danger of contracting rabies, histoplasmosis, and other diseases - there can even be fires and explosions which produce noxious gases. In late 1968, Richard Breisch first described the possibility of a new hazard to U. S. cavers: natural radiation. Subsequently, Jo Bob Trout, Marvin Wilkening and David Watkins measured radon gas concentrations in caves of southern New Mexico, including Carlsbad Caverns. Their results suggested a possible health hazard for NPS cave employees under existing OSHA uranium mining radiation exposure standards.

The National Park Service (NPS) is studying levels of alpha radiation in all NPS administered caves in which tours for visitors are regularly conducted. The NPS research has the dual but complementary objectives: 1) To safeguard health at the NPS administered caves; and 2) To develop data on alpha radiation levels and on natural airflows in NPS caves. The results reported for NPS caves can be used by various agencies to clarify health standards for exposures to low airborne alpha radiation levels in cave environments. These results show daily and seasonal trends and the influence of natural ventilation by air circulation for each cave investigated.

This radiation is produced by the radioactive decay of radon and thoron gases, which in turn result from uranium and thorium decay. These latter elements are found in all terrestrial rocks and soils, in varying though minute concentrations. Acidic rocks and weathered residual soils from such rocks usually contain the highest amounts of these elements. The decay products of the two radioactive gases which constitute a potential health hazard are their short-lived "daughters." These are ionized solids yielding alpha radiation which may become attached to dust and water particles in cave air. When inhaled into the lungs they can cause alpha radiation damage which can lead to lung cancer after prolonged exposures, because the alpha radiation has large ionizing effects on lung tissues. Continuous exposures of many years usually are necessary before atypical cells appear. This has been documented to be anomalously high among uranium miners. Smoking has a contributory effect which greatly increases the radiation health hazard.

Radiation levels (i.e. exposure rates) are measured by the "working level" (WL). One WL is defined as any combination of radon daughters in 1 liter of air which will result in the ultimate emission of 1.3×10^5 MeV of potential alpha energy. The value of the WL is derived from the alpha energy released by the total decay of short-lived daughters in equilibrium with 100 pCi of Rn-222 per liter of air or of 8 pCi of thoron per liter.

The basic exponential decay equation serves to model this radioactive phenomenon:

$$\frac{N}{N_o} = e^{-\lambda t} \text{ ; where:}$$

N = the number of atoms at any time, t.

N_o = the number of atoms at some arbitrary initial observation time, t_o.

λ = the radioactive decay constant for any particular radioactive element. The greater λ is, the more rapid is the decay of the radioactivity.

In differential form this becomes:

$$\frac{-dN}{dt} = \lambda N; \text{ where:}$$

the time rate of decay $(\frac{dN}{dt})$ is conveniently measured by the picoCurie (pCi) per liter of air. 1 pCi = 2.2 disintegrations per minute. λ can be expressed in terms of the half-life, T, of a radioactive element by:

$$\lambda = \frac{0.693}{T} .$$

The T's for the uranium and thorium decay family series have been well established experimentally.

The total exposure accumulated by a person exposed to airborne alpha radiation in any underground environment, whether a man-made mine or a natural cave, is the most important health consideration. This exposure is computed as the product of exposure rate (in WL) and time. The cumulative exposure is measured by the working level month (WLM), defined as the exposure received from breathing air at one WL concentration for 173 working hours per month (40 hrs./work wk.), or any combination of exposure rate (WL) and time which might give 1 WLM.

Radiation health standards are set and enforced by several government agencies: Mining Enforcement and Safety Administration (MESA), National Institute for Occupational Safety and Health (NIOSH), EPA and OSHA. These agencies have assisted NPS in its cave radiation research. The most important health standards derived from uranium mining are probably:

1. Routine, weekly monitoring must be carried out in all underground areas which exceed 0.30 WL and cumulative exposure records must be kept for all employees working in these areas.

2. No employee can exceed 4 WLM cumulative exposure per calendar year.

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[2]National Park Service, Mammoth Cave National Park, Mammoth Cave, Kentucky.

[3]National Park Service, Carlbad Caverns National Park, Carlsbad, New Mexico.

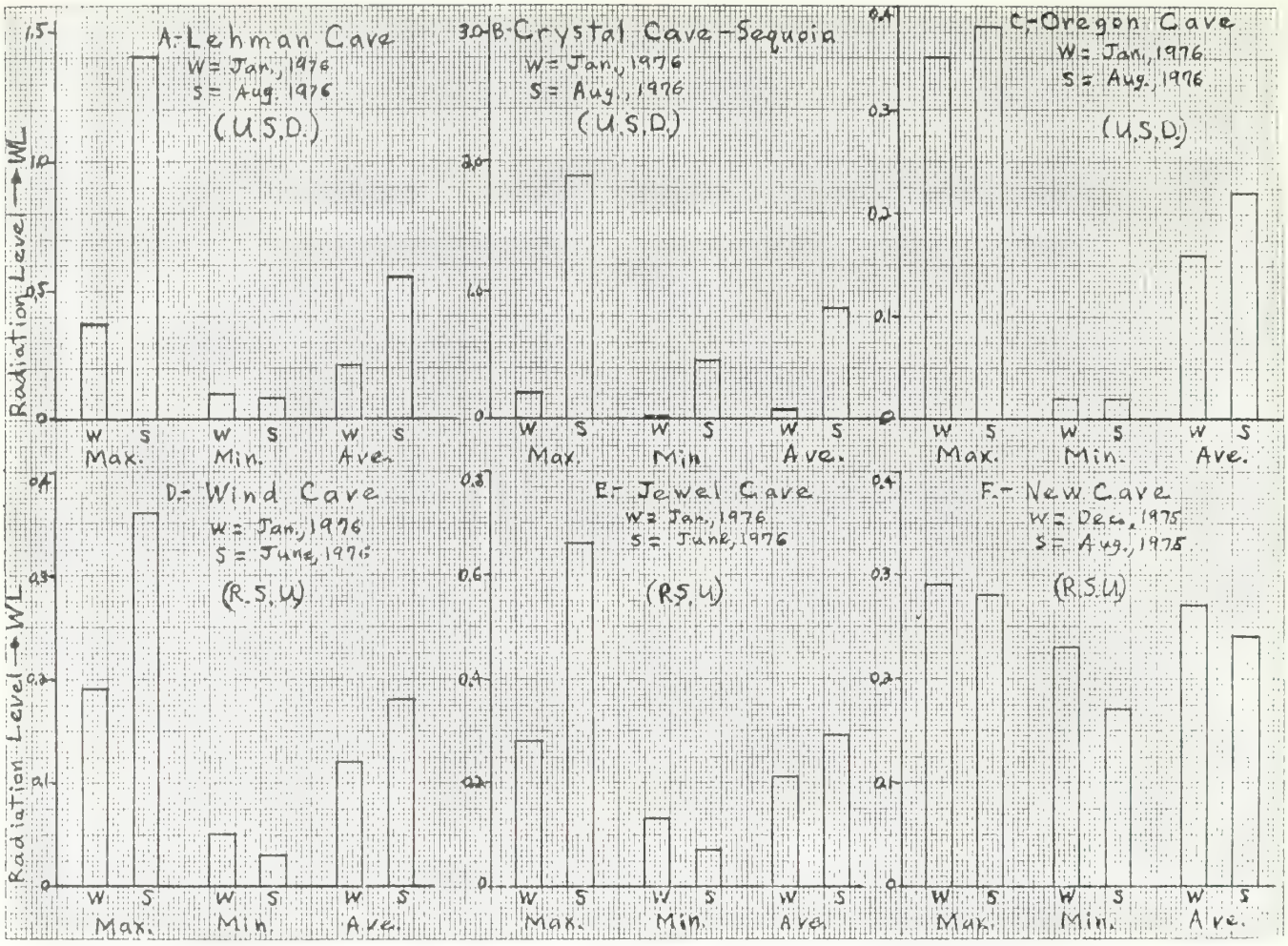


FIGURE 1. Extrema and averages, by season, for NPS caves-radiation.

The airborne alpha radiation is measured by collecting timed samples of the air in work areas using special filters and air pumps. These filtered samples are read for their radioactivity levels in alpha scintillation probe and scaler recording unit. Epidemiological studies among uranium and certain non-uranium miners have shown that the incidence of lung cancer is increased some three times for continuous exposure to greater than 0.30 WL radiation compared to exposures to less than 0.30 WL. Smoking can increase the likelihood of lung cancer some ten times after several years continuous exposure, especially to radiation levels above 0.30 WL. However, there is evidence that the continuous exposure is the significant factor and that lung cancer incidence is not exposure rate dependent. Furthermore, there is no threshold of safety limiting value for the exposure rate.

NIOSH has examined NPA employees from a number of the NPS cave areas for pulmonary cytology. These results have not been reported to NPS in detail as yet. However, preliminary data suggest some atypical cells which may be attributable to the airborne cave alpha radiation. This has yet to be determined much more fully.

Table 1 shows the ranges of exposure rates (in WL) for radon daughter concentrations in the NPS caves which have been investigated. These can be compared with the health standard of exposure rate of 0.30 WL to see those caves in which NPS has initiated routine, weekly monitoring and employee exposure record keeping. Only minute thoron radiation exists.

Figures 1 and 2 (drawn from Table 1 data) suggest seasonal variations based upon the initial data obtained in this investigation to date. From these results it is hypothesized that all caves having minimal man-made disturbances such as tunnels, elevator shafts, bore holes, sealed and closed gates, etc., which would alter the natural cave airflows, experience seasonal variations in airborne alpha radiation. (Also see data from one year's measurements at Carlsbad Caverns in Paper Number 180 by Dr. Gary Ahlstrand and Mrs. Patty Fry). The radiation levels increase in summer but decrease in winter, based upon natural air movements through each cave system. However, the reasons for these seasonal fluctuations depend upon the general cave type of physical configuration and its control of the air-flows.

Thus, of particular importance to the exposure rates in natural caves are the natural ventilation patterns. These airflows are the only means by which the radiation is dissipated or concentrated In mines, forced air ventilation is used to minimize the airborne alpha radiation in order to

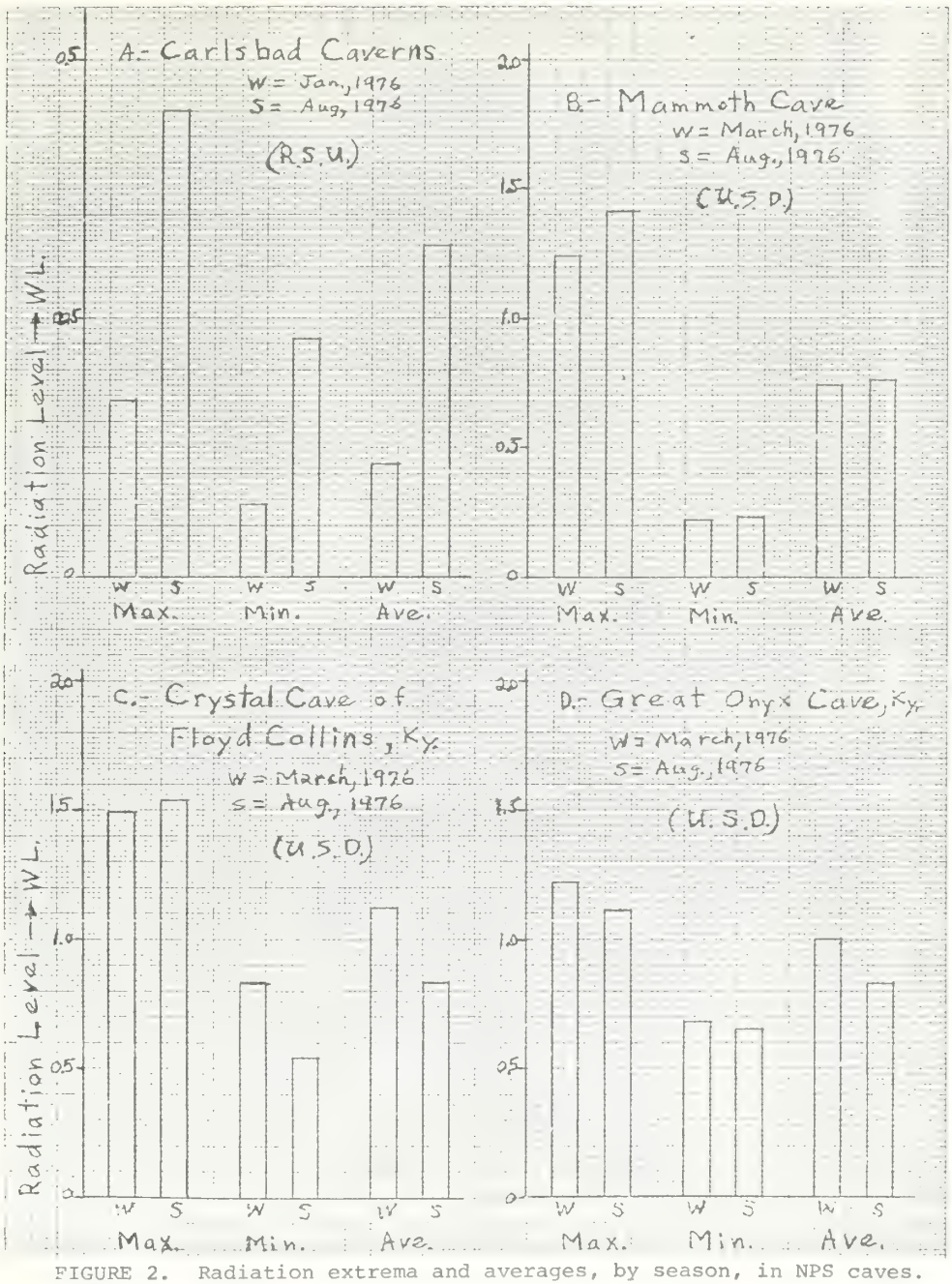


FIGURE 2. Radiation extrema and averages, by season, in NPS caves.

meet the health standards. In caves, although this type of radiation is usually much less, it is not possible to use artificial ventilation because of the adverse effects upon the microclimates of the caves. John McLean of the U.S.G.S. has shown this by his studies at Carlsbad Caverns.

Two general types of cave configurations have been identified for the purpose of relating natural cave airflows and resulting in airborne alpha radiation levels. Figure 3, below, shows these.

Two general results of analyzing the data (see Figures 1 and 2 and Paper No. 180) obtained to date comparing "upside-down" (USD) and "right-side-up" (RSU) cave airflows and ventilation (only on the toured routes), are:

1. Measurement of the airborne alpha radiation in caves must be accompanied by airflow and meteorological measurements to describe the physical microclimatic characteristics of each cave and to relate these to the outside meteorological patterns of the area in which the cave is located. The two--radiation and airflow--are inextricably linked and complementary. Indeed, radiation is a "tracer" for airflow and indicates its general tendencies.

2. Both general configurations of caves experience increase in the summer, compared to the winter, in an overall sense, but for different reasons which have been hypothesized for the limited data. In "upside-down caves," this summer increase is produced by air flowing out of such caves' lowest portal(s)--

TABLE 1. Summary of radon daughter concentrations in NPS caves.

Part A: Cool Weather Measurements:

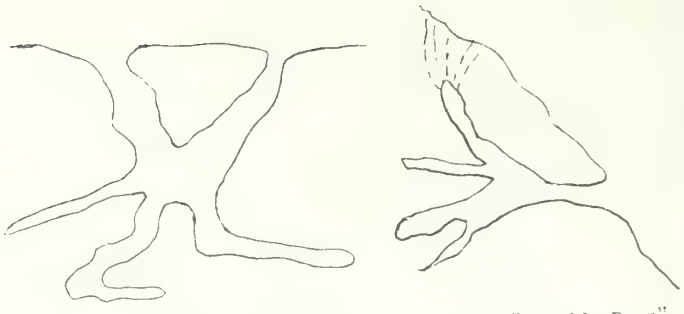
Cave	Working Level Measurements (WL) Maximum	Minimum	Weighted Avg.
Carlsbad Caverns, New Mexico: (Sampled on Nov. 4-7, 1975 by MESA)	0.3		
Toured areas open to visitors:			
1) Main corridor and Scenic Rooms	0.36	0.04	0.25
2) Big Room	0.40	0.20	0.30
3) Lunch/Pump Room	0.36	0.17	0.26
Lower cave-not visited by tours	0.99	0.33	0.65
New Cave, New Mexico: (Sampled on March 8, 1976)	0.35	0.27	0.20
Timpanogus Cave, Utah: (Sampled Jan. 5, 1976)	0.02	Trace (0.003)	0.01
Lehman Caves, Nevada: (Sampled Jan. 6-8, 1976)	0.37	0.10	0.21
Wind Cave, South Dakota: (Inner reaches of Tour Route) (Sampled on Jan. 19, 1976, by MESA Field Office in Rapid City, SD. Only trace values were found in outer reaches of Tour Route)	0.19	0.05	0.12
Jewel Cave, South Dakota: (Sampled by MESA Jan. 19, 1976 along Tour Route)	0.28	0.13	0.21
Crystal Cave, Sequoia National Park, California: (Sampled Jan. 21-22, 1976)	0.22	Trace (0.003)	0.07
Marble Cave, Sequoia National Park, California: (Sampled Jan. 23, 1976)	0.01	0.01	0.01
Oregon Caves, Oregon: (Sampled Jan. 24-26, 1976)	0.35	0.02	0.16
Lava Tube (Valentine) Cave, Lave Beds National Monument, California: (Sampled Jan. 27, 1976)	0.13	Trace (0.003)	0.07
Round Spring Cave, Ozark National Scenic Riverways, Missouri: (Sampled Feb. 14-15, 1976)	0.60	Trace (0.003)	0.29
Mammoth Cave, Kentucky: (Sampled Mar. 26-30, 1976; all tour routes included here)			
New Discovery Cave, Kentucky: (Sampled Aug. 4-5, 1976 by NPS and MESA)			
1) MESA measurements	1.19	0.87	0.99
2) NPS measurements	1.10	0.97	1.04
Floyd Collins' Crystal Cave, Kentucky: (Sampled Aug. 3-5, 1976)			
1) MESA measurements	1.48	0.87	1.22
2) NPS measurements	1.54	0.54	0.75
Great Onyx Cave, Kentucky: (Sampled Aug. 3-4, 1976)			
1) NPS measurements	0.89	0.75	0.82
2) MESA measurements	1.11	0.65	0.84
Wind Cave, South Dakota: (Sampled June 7-10, 1976; all tour routes included here)			
1) NPS measurements	0.29	0.06	0.18
2) MESA measurements	0.36	0.03	0.18
Jewel Cave, South Dakota: (Sampled June 8-9, 1976; all tour routes included here)			
1) NPS measurements	0.27	0.07	0.24
2) MESA measurements	0.66	0.10	0.32
Big Horn Cave, Montana/Wyoming: (Sampled by MESA June 29, 1976)	0.73	0.36	0.52
Features at Wupatki/Sunset Crater, Arizona: (Sampled June 30-July 1, 1976)			
1) Blowholes	0.25	0.07	0.14
2) Earthcracks	0.55	0.05	0.32
3) Ice Cave	Trace	Trace	Trace
Selected Caves at Grand Canyon National Park: (Sampled July 7-16, 1976)			
1) Stanton's Cave	3.28	1.08	2.05
2) Bat Cave	3.45	0.95	2.50
3) Sand Cave	0.27	0.21	0.23
Crystal Cave, Sequoia National Park, California: (Sampled Aug. 8-9, 1976)	1.88	0.43	0.86

1) MESA Measurements	1.00	0.30	0.65
2) NPS measurements	0.88	0.24	0.49
Great Onyx Cave, Kentucky:			
(Sampled Mar. 29-30, 1976)	1.22	0.68	1.00
(Sampled Apr. 22, 1976)			
1) MESA measurements	0.80	0.57	0.72
2) NPS measurements	0.76	0.48	0.62
Floyd Collins' Crystal Cave, Kentucky:			
(Sampled Mar. 29-30, 1976)	1.49	0.83	1.12
(Sampled Apr. 22, 1976)			
1) MESA measurements	1.45	0.79	0.95
2) NPS measurements	1.29	0.70	0.87
White Cave, Kentucky:			
(Sampled Apr. 22, 1976)			
1) MESA measurements	0.64	-	-
2) NPS measurements	0.52	0.45	0.49

Part B: Warm Weather Measurements:

Mammoth Cave, Kentucky:			
(Sampled Aug. 3-5, 1976 by NPS and MESA; all tour routes included here)			
1) MESA measurements	1.41	0.23	0.76
2) NPS measurements	1.04	0.26	0.65
White's Cave, Kentucky:			
(Sampled Aug. 3-4, 1976 by NPS and MESA)			
1) MESA measurements	1.18	0.60	0.76
2) NPS measurements	1.22	0.58	0.77
Lava Tube (Valentine) Cave, Lava Beds National Monument, California:			
(Sampled Aug. 10, 1976)	0.09	0.03	0.06
Oregon Cave, Oregon:			
(Sampled Aug. 11-12, 1976)	0.38	0.02	0.21
Timpanogos Cave, Utah:			
(Sampled Aug. 13-14, 1976)	0.08	Trace	0.03
Lehman Cave, Nevada:			
(Sampled Aug. 15-16, 1976)	1.40	0.08	0.55
Carlsbad Caverns, New Mexico:			
(Sampled Aug. 24-26, 1976 by MESA and NPS)			
Toured Areas Open to Visitors:			
1) Main Corridor and Scenic Rooms			
NPS measurements	0.33	0.24	0.30
MESA measurements	0.38	0.24	0.30
2) Big Room			
NPS measurements	0.36	0.28	0.33
MESA measurements	0.41	0.31	0.38
3) Lunch/Pump Room			
NPS measurements	0.40	0.38	0.39
MESA measurements	0.39	0.31	0.35
Non-toured Areas, Closed to Visitors: (Lower Cave, New Mexico Room, and Left-hand Tunnel)			
NPS measurements	0.96	0.21	0.55
MESA measurements	0.92	0.09	0.40
New Cave, New Mexico:			
(Sampled Aug. 25-26, 1976)			
1) NPS measurements	0.24	0.21	0.23
2) MESA measurements	0.28	0.17	0.24
Spider Cave, New Mexico:			
1) NPS measurements	0.47	0.19	0.37
2) MESA measurements	0.51	0.20	0.37

usually in a diurnal cyclic process. In "right-side up" caves the summer increase is due to the fact that the air does not flow. This is not a paradox, however--simply a result of the physics of each situation. In general, therefore, all caves of whichever configuration experience increases in airborne alpha radiation in the summer compared to the winter, as long as there has been little or no man-induced disturbance to the caves' airflow patterns.



A. "Right-Side-Up" Cave Type

B. "Up-Side-Down" Cave Type

FIGURE 3. General cave configuration types determining natural airflows. The measurement of radon daughter radiation levels serves as a useful means to describe air flow patterns, in addition to employing the methods of fluid mechanics.

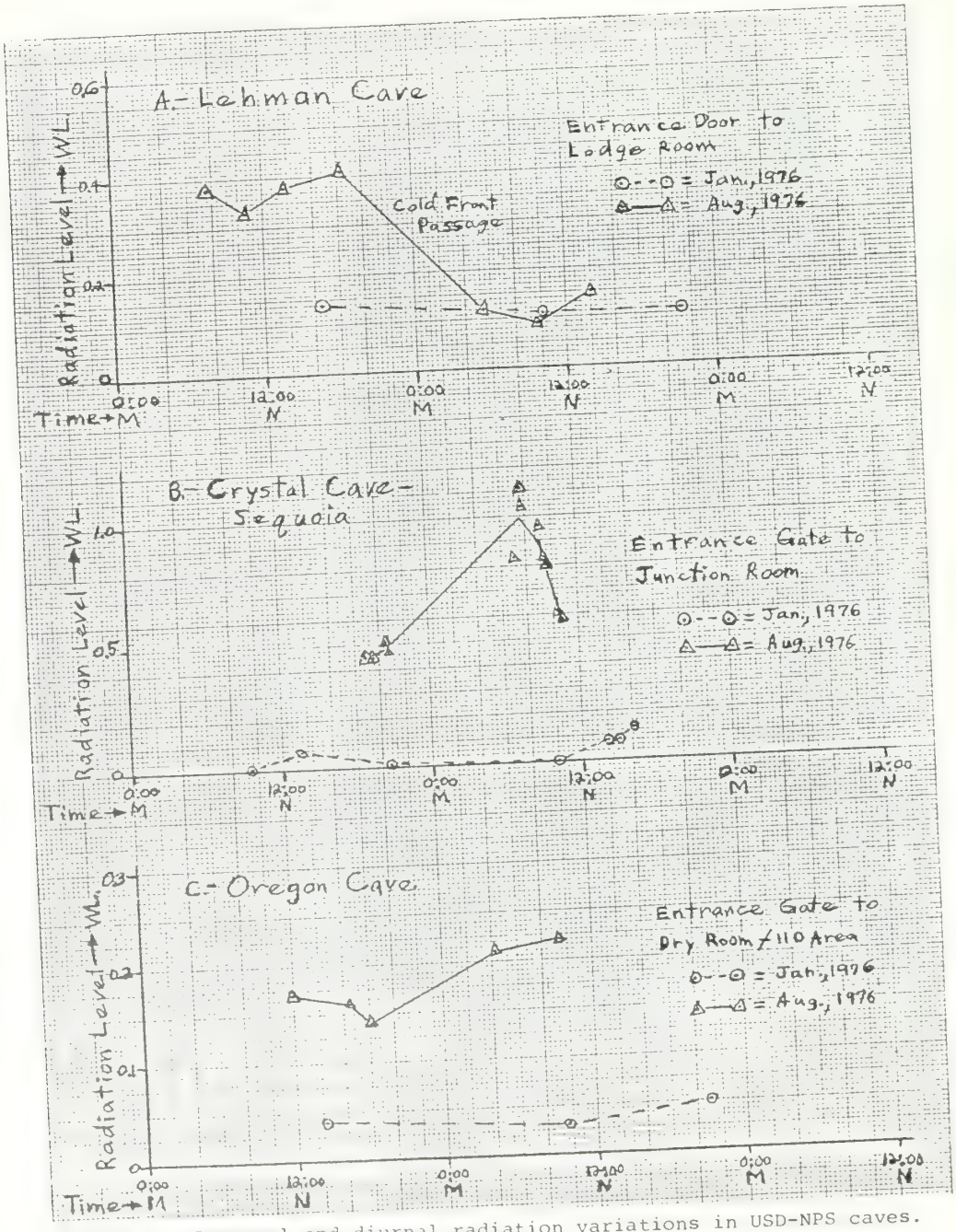


FIGURE 4. Seasonal and diurnal radiation variations in USD-NPS caves.

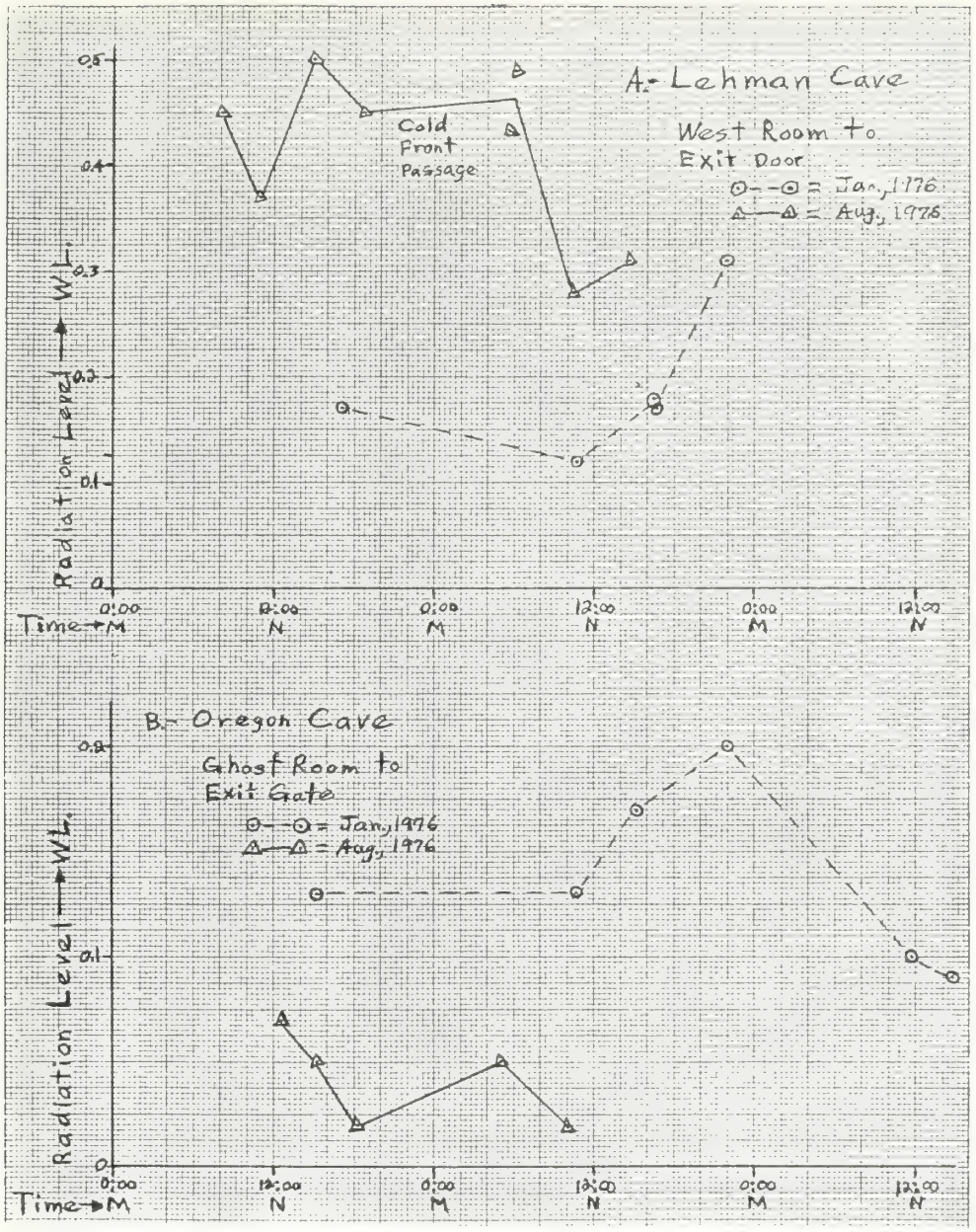


FIGURE 5. Effects of man-made access facilities in NPS cave on radiation--with seasonal and diurnal variations.

Interesting diurnal as well as seasonal interactions of airflows and radon daughter levels have been observed to date in three USD type caves: Lehman, Oregon, and Crystal in Sequoia. Similar data for such USD Caves as Mammoth and the several connected to it: Floyd Collins' Crystal, Great Onyx and New Discovery have yet to be obtained. Also, data for RSU caves such as Wind and Jewel, Carlsbad Caverns, and New Cave are not fully available as yet. Work on this is proceeding in order to test the hypothesized seasonal radiation/airflow behavior of USF vs. RSU caves. In addition, the initial data already taken at Mammoth and its connected caves and at Oregon Cave show the effects of human management actions.

These general observation were obtained from the following more detailed considerations:

1. The importance of the effects of natural airflows on cave radiation has been emphasized repeatedly. The basic rule of thumb is that increased radiation occurs when cave air stagnates but decreased radiation occurs in the immediate vicinity of moving cave air, in general. However, the analysis given below in this section describes apparent paradoxes to this and explains why they occur. Nevertheless, it seems generally true that airflow decreases airborne radiation while stagnation increases it. Any apparent paradoxes result from how the air moves through a cave system with respect to time, as will be explained in the subsequent discussion. In order to compare the effects of natural and man-induced airflow ventilation in USD caves having no portal sealing versus seasonal portal sealing versus year-round portal sealing, for both the winter and summer diurnal airflow cyclic process situations, Figures 4 and 5 have been prepared. The bar diagrams give more gross comparisons. The caves chosen for comparison are Crystal in Sequoia, Oregon, and Lehman. These are all smaller caves in which the airflow patterns are more easily definable. While Mammoth Cave and its interconnected caves: Crystal (or Floyd Collins) and Great Onyx are all part of an immense system which is, in general, of the USD configuration--venting out at the natural Historic Entrance--the system is too complex to analyze clearly with the data presently available. This can be seen in the bar graphs of Figure 2, B, C and D which show gross comparisons. For all three Mammoth Cave area caves the extrema are about the same in winter and in summer, except the minima for Crystal where the summer value is much lower than the winter value. However, although the averages for Mammoth are about the same, with the summer only slightly higher than winter, the summer averages for both Floyd Collins' Crystal and Great Onyx are lower than the winter averages. All three of these vent out through their portals, though the entrances at Crystal and Great Onyx are solid doors which provide considerable sealing effect. Crystal has another portal at the Austin entrance which is unsealed and from which air vents outward strongly in warm weather.

2. The management procedure at Oregon Cave and Mammoth Cave (both USD) is to put up seals over the entrances and exit doors in mid-fall and remove these in mid-spring each year. This minimizes the cold airflow and resulting chill of visitors. As a result, the winter and summer radiation levels are about the same, even though the airflows are much greater in summer than in winter. These airflows mobilize radiation materials from much greater extents of the caves' systems in summer than in winter. However, the sealing doors decrease the discharge in winter, when airflows mobilize radiation materials from lesser extents of the caves' systems. Thus, this sealing action permits radon daughters to approach equilibrium more closely and to elevate the radiation levels so that the summer values are approached. Because Floyd Collins' Crystal Cave and Great Onyx Cave are both connected by a vast (some 180 mile) cave system to Mammoth Cave and because both caves have solid steel doors which produce partial air seals in their entrances, their winter values actually exceed the summer values in an accentuated example of the "sealing" effect of door covering. The entire system drains air downslope to the natural ("Historic") entrance of Mammoth.

Crystal Cave in Sequoia has only one year-round unsealed portal but air can enter its upper reaches through fissures. It has a short tunnel in its inner reaches but this has not altered the general, natural airflow patterns appreciably. Oregon Cave has two entrance portals and one man-made exit tunnel portal, each of which is sealed during the winter months but not in summer. Lehman Cave has man-made tunnels at both its entrance and exit. These are closed by pairs of solid doors at each end of each tunnel. These are fairly airtight. This minimizes the disruption of the natural airflow patterns. The natural discovery entrance at Lehman is not sealed and various fissures and blowholes also still permit air fluxes. Thus, the original airflow and venting characteristics of Lehman Cave are probably not too greatly altered by the two man-made tunnels, because of the double doors. This is not the case at Oregon Cave, however; because the man-made tunnel is left unsealed in warmer weather and forms the major portal for airflows to enter the cave system and to flow downhill inside the cave; thereby flushing out the radiation.

The bar diagrams in Figures 1, A, B and C show a large increase in summer radiation for both the maxima and average values at both Lehman and Crystal Caves, compared to their winter values. This is not true for Oregon Cave, which has the pronounced man-made tunnel induced airflow effect in summer. This effect is greatly precluded in winter by sealing all the cave's portals--the two natural entrances and the exit tunnel gate. By contrast, the double doors on Lehman Cave's entrance and exit tunnels preclude most airflows year-round and cause it to act very much as an undisturbed cave, such as Crystal Cave in Sequoia is.

Though the air can move into each of these three caves, especially in the summer in a more extensive way than in winter, the existence of the exit tunnel at Oregon Cave promotes flushing out of the radiation materials in summer, but not in winter when it is sealed. Therefore, the average and maximum summer levels are slightly increased. While this increase is small, it still indicates the trend and tendency of all USD caves left in their basically natural state to show increased summer levels. However, the radiation levels rise dramatically in both Lehman and Crystal Caves in summer because air continuing to move into the upper reaches of each tends to become laden with radiation, which fluctuates in level as it is affected by the diurnal airflow cyclic process. The minima rise in Crystal but fall slightly in Lehman from winter to summer due to differences in the effectiveness of the overall airflows. Thus, the radiation levels rise in evening, at night and early morning during the summer but are flushed out and fall in late morning, during the day and sometimes into early evening. Figure 4 shows this as well. Figure 5 emphasizes the effect of sealing the portals at Oregon Cave by showing that the winter levels exceeded those of summer. This is the only instance of this "reversal."

Nevertheless, the overall effect of the daily airflow cycle is to increase the summer radiation levels over those in winter in caves for which the basic natural flow patterns have not been altered by man. This was precluded at Oregon Cave due both to the existence of the man-made exit tunnel and the management decisions to seal it in winter and open it in summer. At Lehman Cave, the natural airflow processes (and probably the natural

microclimate) of the cave are basically undisturbed by the two man-made tunnels which remain sealed at all times. The main advantage of the operation at Oregon Cave seems to be to suppress the radiation level in the summer below the values which it might attain. (This also enhances access by bats.) However, this may be at the expense of the cave's natural integrity: its microclimate. All of this shows man-caused effects versus those which are natural. Comparison of Figures 1, A, B and C and 4, A, B and C shows this most clearly. In Figure 5 the summer values are actually below those of winter due to the strong and continuing air inflows at the exit gate.

3. In the winter time at such USD caves as Lehman and Crystal in Sequoia, and Oregon too, the airflow is much less. It occurs to some extent in the mid- to late afternoons of warm, sunny days. This begins the overall cyclic process, but it is shifted in time in winter compared to summer (see Figures 4 and 5). In winter the outcast airflows and resulting increases in radiation do not occur until late afternoon and early evening. The rise in radiation does not last very long before the outside air cools below the cave air temperature and outside air then flows into the cave, diminishing the radiation in the areas closest to the portals through which the air is moving. The toured parts of the three caves discussed here lie in these areas of diminished winter radiation.

In summer, the airflow process begins earlier in the day, and lasts much longer (see Figures 4 and 5). However, the overall pattern of cyclic airflow from stagnation, to increase, to stagnation again (or, instead of stagnation, perhaps very low airflows, either incast or outcast depending on the cave) causes the typical cycle of radiation: decrease into late morning or early afternoon to even early evening, with an increase from night to early or even mid-morning. The differences; as shown by comparing Figure 4 A for Lehman Cave, with Figure 4 B for Crystal Cave in Sequoia, and with Figure 4C for Oregon Cave; are due to the unique characteristics of each, but the basic fall-rise-fall rhythm of the airflow induced radiation level fluctuations can still be seen. This persists even after the cold front passage at Lehman altered the radiation levels. This front changed the outside weather from hot summer to crisp spring, though sunshine persisted throughout both the two August days, 1976.

All very good--but how come the summer radiation levels in these USD caves are higher than in winter, just as occurs in RSU caves, such as Carlsbad, Wind and Jewel? In USD caves it appears that the radiation levels increase in summer because the airflow does occur in a strong way, but in RSU caves it appears that the radiation levels also increase in summer, but because the air tends to stagnate (except for weather front passages which may induce some airflows). How can this be?

The seeming paradox is explained by considering how the air tends to flow in each general cave configuration type: USD versus RSU. In the USD type, the airflow process is cyclic and unsteady, in general (except as perturbated by weather systems inducing pressure changes and thus, pressure produced airflows superimposed on the cave's general gravity airflows). However, in winter these cyclic flows are of short duration and occur only near the cave's portal(s). In winter, although air may sink into the cave's upslope, it takes it a long time; i.e., perhaps several days of cyclic actions, which may be interrupted by cloudy weather; to travel to the portal(s). Thus, the airflows mobilize small total amounts of air in winter and move these to the toured areas where the measurements are made. Therefore, even if in radioactive equilibrium, per unit volume, the concentration (i.e., radiation per unit volume of air in pCi/l) levels are less. However, in summer, air moves from the extremities more quickly moving greater total quantities of radiation in shorter time periods to the toured areas. Hence, the concentrations measured there are higher in summer than in winter.

On the other hand, the RSU cave types have more sustained and steadier airflows in winter because then the colder more dense outside air sinks into the cave, displacing its comparatively warmer, less dense air and flushing out the radiation. This process continues in a long-term fashion (as Paper No. 180 for Carlsbad shows) so that the winter radiation levels are lower than in summer. Indeed, the airflow in RSU caves can be greater at night than in the daytime since the outside air temperature is lower at night. In summer, the reverse of this process occurs, and the cave air, being comparatively colder and denser than the outside air, tends to stagnate. Hence, the radiation levels can build up and become higher than in winter (see Figures 1, D, E and F and 2 A for example). Of course, as in USD caves, the effects of passing weather fronts can perturbate a RSU cave and produce airflows in summer which overcome the stagnation to some extent. In winter, these can augment the gravity flows and depress the radiation levels further. Indeed, it can be speculated that the fluctuations on long-term plots might be the superposition of pressure produced airflow/radiation level oscillations on the long-term gravity airflow/stagnation situation.

Therefore, the basic radiation/airflow difference for the two cave configuration types, USD versus RSU, is due to how the air moves with respect to time and over space. Both cave types experience increased summer radiation levels, for different physical reasons. The only exception is a cave, such as Oregon Cave, which is affected by man-made portals and/or management procedures. Figure 5 emphasizes the effect of sealing in winter because then radiation near the exit is less than in summer (despite any air leakage which may occur through the winter seal). Comparing Figures 5 A and B, the winter increase in the latter is due to the sealing effect whereas the winter decrease in the former is due to outcast air leakage in winter.

Therefore, in general, airflows tend to reduce radiation levels in localized areas and short times in all caves, but long-term seasonal effects are produced by cave configuration. Conversely, localized stagnation of air in all caves leads to localized, short-term radiation level increases, but long-term seasonal effects again result from cave configuration. Paradoxically, increases occur in summer in all caves: because the air flows in the USD type and because it does not flow in the RSU type. It is all a matter of configuration and season. Further work on this, especially making radioactive equilibrium and age of air measurements as well as radiation observations seasonally and over time at different places in the caves is needed for more complete confirmation of these ideas.

4. The bar diagrams for all four RSU caves show the RSU cave radiation level seasonal fluctuations. This has already been described above. The bar diagrams, Figures 1 D and 1 E, show that although the summer and average maxima exceed those for winter, the summer minima are less than the winter minima in Wind and Jewel Caves. This suggests that the pressure produced airflows in certain parts of each cave produce the lower summer minima because they are greater than in winter. The situation at New Cave, Figure 1 F, is not understood--as to why all its winter values exceeded those of summer. Although a RSU cave, perhaps it has some special, as yet undetermined, airflow situation. Nevertheless, the W and S values are about the same. Perhaps air pressure effects caused these results, which more complete data analysis can clarify. Whether there is any diurnal cycling remains to be shown by future work. Perhaps data plots such as Figures 4 and 5 will result. If so, this would suggest that pressure induced airflows in RSU caves can produce radiation level fluctuations similar to the temperature induced gravity flows of USD caves. Wind Cave and Jewel Cave have RSU configurations and outward venting at their portals which is produced primarily by pressure effects of passing large-scale storm frontal systems in the outside atmosphere. Secondary effects of venting stem form seasonal outside air temperature changes and resulting air movements into the cave, as at Carlsbad Caverns. These frontal sytems cause strong outcast airflows through the portals of both these caves, especially Wind Cave (hence its very appropriate name). This is how it was discovered. Long-term radiation data will be useful in establishing seasonal trends. These data, along with meteorological measurements, will be made in future work starting in mid-December 1976. The detailed effects of passing frontal systems can then be quantified, hopefully. The seasonal variations at Wind and Jewel Caves show that summer maxima and average levels exceed the winter values in these caves, but that the summer minima are less than the winter minima for each cave. All this is reasonable because the RSU configuration produces summer stagnation situations and the resulting buildup of radiation materials which are not vented out as often as during the winter. Thus, the higher maxima and overall averages. However, the frontal system pressure fluctuations tend to be stronger in the summer, so that the minima are lower than in winter in some parts of these caves due to more efficient flushing when pressure airflows do occur in the summer. Carlsbad Caverns, also a RSU cave, is subject to the passage of frontal systems. However, much of the variation in its radiation levels is produced seasonally by outside to inside air temperature differences. In late fall, winter and early spring the outside air temperatures are less than the cave air's year-round average of 56°F. The cooler, more dense outside air sinks into the cave through its portals and fissures and displaces the warmer cave air. This leads to venting and a reduction of the radiation level. In warmer seasons, especially in summer, the outside air is warmer and less dense than the cave's air. Therefore, no density induced displacement occurs and instead the cave's air tends to stagnate. The radiation levels tend to rise. Only the effects of weather frontal systems passing with resultant air pressure pulsing will cause venting during the warmer seasons.

5. The airflow from both Mammoth Cave and Carlsbad Caverns had at one time been used to air condition surface buildings. This practice has been terminated to preclude adverse effects on the caves' microclimates and to eliminate airborne alpha radiation in these buildings. Carlsbad behaves in the expected RSU manner with summer increases in radiation. The situation at New Cave is not clear. Although it is RSU, its entrance is not sealed. The data here are limited as yet. All of this (see Figures 1, A, B and C) shows the effects which man's interference and/or management activities has on caves--using the airborne radiation/airflow observations as a yardstick. This sealing activity also affects the access which bats can have to caves.

6. The general airflow pattern shows outcast flows through the natural Historic Entrance of Mammoth Cave and the entrances of other nearby caves (Crystal, Great Onyx, etc.) of any size during the day when the cooler cave air is denser than the warmer outside air. The main flow is out the Mammoth Cave entrance. This gravity flow indicates that the overall Mammoth system is an USD cave of immense proportions, sloping down elevation gradient to the several portals in the park. Its known physical configuration supports this. This outward venting is very strong during the warmer days of summer, but is lessened during the passage of cold fronts.

The flow patterns must be defined in much more explicit detail in order to describe the complex situation. This will be done using meteorological equipment. The levels increase somewhat in summer in some areas but decrease in others, as compared with winter values, due to airflow. Nevertheless, the overall tendency seems to be an increase in winter and a decrease in summer in Crystal and Great Onyx Caves which are less well vented in winter, but little changes in the overall levels at Mammoth Cave.

The permanent personnel at Mammoth Cave have been rotated as to work area assignments to reduce cumulative exposures. Most spent the summer working above ground while seasonal personnel conducted tours or worked at various stations underground on the self-guided tour routes.

7. Wind and Jewel Caves (both RSU) are of the "down-into" type instead, as their physical configurations show. The wind movements are attributed by NPS staff at each cave more to the passage of weather frontal systems with the accompanying outside atmospheric pressure fluctuations than to the configuration of the caves. Thus, the flows are more pressure gradient induced than being solely gravity flows. Meteorological equipment will be used to check the inside and outside conditions in these caves in order to quantify the airflow patterns and behavior.

Although the data of early June 1976 probably are not representative of true summer conditions, they do show a general increase over the winter values of January 1976. Airflows are due to the combined interactions of outside pressure effects and the overall RSU configuration of both caves. The flows out from the portal of Wind Cave are especially strong; hence its name. These may tend to suppress the radiation levels at both caves in the summer, especially in Wind Cave (see Table 1), though the increase of summer over winter values still occurred. Therefore, neither could be of the USD type. See Figure 1 for seasonal changes.

8. The outcast airflows of Crystal Cave in Sequoia (USD) increase during the day and

decrease at late night and very early morning in summer. The radiation is flushed out by mid-day and the levels fall and remain low until late at night when the outside air cools and the outcast airflow diminishes. This same diurnal cycling process was observed to some extent in the winter on warm, sunny afternoons, but is very pronounced during the summer. It is interrupted only by the passage of cold fronts, but is reestablished in a day or two of subsequent clear weather. This is the same as also observed at Mammoth Cave, where it is on a much larger and more complex scale.

9. At Oregon Cave (USD), because the entrance and exit portals are sealed in winter to preclude the entry of cold airflows, the airborne radiation levels in parts of this cave tend to rise. Airflows do develop in winter to some extent on warmer sunny late mornings and afternoons. However, in summer the sealing covers are removed from all the portals so that the airflows increase. This flushes out the radiation in a diurnal cycling process similar to that of Crystal Cave in Sequoia. Therefore, the management decision on sealing or not sealing the portals greatly affects the radiation levels. It can only be speculated as to how high the radiation levels might become in the summer if the portals remained sealed. However, if the seals remained on in summer, the levels might exceed 0.30 WL considerably in some parts of the cave's toured regions, based on the winter and summer (early morning with no airflow) data. Keeping the seals on would also tend to reduce evaporation in the cave, which no doubt affects its microclimate. Studies at Carlsbad Caverns have shown that man-induced airflows will have these effects. At Oregon Cave, the man-made exit tunnel seems to enhance the airflows through the entire cave considerably, especially during the summer when it is unsealed. On the other hand, unsealing does not seem to produce airflows from a greater extent of cave, as happens at Sequoia's Crystal Cave. Thus, the levels at Oregon would not rise much in summer, indicating a smaller cave system.

10. Lehman Cave (USD) has greater diurnal cyclic venting and radiation level fluctuations in the summer than in the winter. The man-made entrance and exit tunnels are sealed by double doors (one at each end), so that these are fairly airtight. Also, several blowholes and the natural "discovery" entrance permit air to flux in and out of the cave system. Therefore, it behaves similarly to Crystal Cave in Sequoia with radiation level buildups during the night in summer and a flushing out decrease during the day. The winter seems to be the reverse of this in general, though the overall radiation levels are less in winter than in summer. (See Figure 1 A.) Meteorological equipment is being obtained to evaluate these processes for Lehman Cave. Cold front passages alter the diurnal cycling of the summer by affecting the airflows. Therefore, part of the airflows is probably an interaction of pressure effects and seiching with the gravity flow.

11. Little radiation has ever been found at Timpanogos Cave, though its summer values (not plotted) are somewhat higher than in winter. Its configuraiton is neither RSU nor USD, but is more "straight through"; being located on a mountainside, it parallels a deep creek ravine, but has little elevation change throughout its length. Air moves through it readily, flushing out any radiation. Nor has any appreciable radiation been found in volcanic areas (as the lava tube caves at Lava Beds in California, or the ice cave in the lava flow at Sunset Crater in Arizona), though thermal areas such as Hot Springs in Arkansas (data not shown here) have high radon daughter levels in enclosed cisterns. This dissipated quickly in the open air. (Yellowstone's thermal formations have yet to be observed for airborne radiation.)

12. The thoron daughter levels were trace to very low in all NPS caves investigated. Hence, this source of alpha radiation is no problem.

LITERATURE CITED

BECKMAN, ROBERT T. 1975. "Calibration Procedures for Radon and Radon-Daughter Measurement Equipment." MESA-IRI005. 47 pp.

BREISCH, RICHARD L. 1968. "Natural Radiation in Caves." Southwestern Caver. VII:5:81-110.

MCLEAN, JOHN S. 1971. "The Microclimate in Carlsbad Caverns, New Mexico." USGS report to NPS, No. CACA-N-1a.

MCLEAN, JOHN S. 1976. "Factors Altering the Microclimate in Carlsbad Caverns, New Mexico." USGS Open-file Report No. 76-171.

MINING ENFORCEMENT AND SAFETY ADMINISTRATION (MESA). 1975 and 1976 editions. "Radiation Monitoring." Radiation Group, Denver Technical Support Center. 88 pp.

ROCK, ROBERT L. 1975. "Sampling Mine Atmospheres for Potential Alpha Energy Due to the Presence of Radon-220 (Thoron) Daughters." MESA-IRI015. 15 pp.

TROUT, JO BOB. 1975. "An Investigation of Radon Levels and Air Exchange Characteristics in Cottonwood and Jurnigan Caves." Southwestern Caver. XIII:3:1-27.

WILKENING, MARVIN H. and DAVID E. WATKINS. 1976. "Air Exchange and 222 Rn Concentrations in the Carlsbad Caverns." Health Physics. 31: 139-145. (First communicated in draft form in June, 1975).

ALUMINUM PRECIPITATION, BEECH FLATS AND WALKER'S PRONG CREEKS, GREAT SMOKY MOUNTAINS NATIONAL PARK

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INTRODUCTION

In early 1973, a low level acid pollution problem was defined within Great Smoky Mountains National Park. Questions asked about the toxicity of this acidic leachate over several miles of potentially excellent trout habitat within two small mountain streams (Figure 1), Beech Flats Creek receiving acid leachate due to the actions of man, and Walkers Prong Creek which naturally receives acid leachate, resulted in implementation of a wide range of biological, chemical, and geological studies. A portion of these studies aimed at defining and understanding this event both in natural and factitious systems is presented here.

Fish and Wildlife personnel performing creel surveys first noted that these streams were incapable of sustaining healthy brook trout populations. Follow-up investigations of their observations yielded evidence of unusually low pH levels within portions of these two streams. The effect of the dilute leachate upon the trout was noted to be toxic in basket tests. Symptoms ultimately proving fatal to test fish were hypersecretion of mucus gill membranes (Huckabee, J. W. et al. 1975).

The sources of acid leachate were traced owing to the characteristically low pH. The leachate was found to emanate from road fill materials, new exposure at road cuts, and natural outcrops (Herrmann, R. et al. 1975). The related rock materials were identified as the Anakeesta Formation, a pre-Cambrian geological unit within the Great Smoky Mountains Group and OCOEE series.

GEOLOGICAL CONSIDERATIONS

The sequence of pre-Cambrian rocks making up the Ocoee Series is representative of a complex stratigraphy of several depositional environments of underwater deposits within a large marine basin. The Ocoee Series is broken into three named groups and additionally contains an unclassified sequence of rocks (from youngest to oldest): Walden Creek Group, Unclassified - Series, Great Smoky Mountain Group, and Snowbird Group. The Anakeesta Formation is one of four formations within the Great Smoky Mountain Group (from youngest to oldest): Unamed Ss, Anakeesta Formation, Thunderhead Ss, Elkmont Ss.

The Anakeesta, as described by Hadley, et al., (1963) and King, et al., (1968), comprises part of the thick sequence of clastic metasedimentary rocks which outcrop throughout the Great Smoky Mountains Region. The unit occurs as discontinuous and isolated patches forming steep ridges and pinnacles, such as the chimneys within Great Smoky Mountains National Park. Separation is partly due to faulting and folding, but mostly the spacial relationships are due to the interfacing of lenses of Anakeesta within the dominantly sandstone body which characterizes the Great Smoky Mountains Group.

The lithology of the Anakeesta Formation is characterized mainly by dark argillaceous metasediments with degrees of alteration ranging from slate to phyllite and shist. Iron sulphides within the unit produce characteristic rusty weathering surfaces. The occurrence of chemically unstable iron sulphide minerals led to the environmental concern which resulted in this study.

BIOLOGICAL CONSIDERATIONS

Macroinvertebrate data were collected to test the hypothesis that toxic products exist in stream waters. The effects upon macroinvertebrate populations were documented (Green, 1975) and important trends are summarized here.

Monthly macroinvertebrate collections were obtained during the period of June 1973 to May 1974, at three sites on Beech Flats Creek and three sites on Walkers Camp Prong (Figure 1), by taking surber square-foot samples in riffle areas and bottom-kicknet samples from riffles and pools. Organisms from surber samples were identified to the lowest practical taxonomic level. Community structure analyses included density (number/m2), biomass (mg/m2), diversity ($\bar{H}$, Brillouin, 1962), and evenness (J', Pielou, 1966). Significance tests employed the student "t" after Li (1969).

Beech Flats Creek

Beech Flats Creek benthic macroinvertebrate communities were represented by a total of 53 taxa at site 1, 41 at site 2, and 47 at site 3. The community at site 1 was characterized by a well developed fauna having a balanced assemblage of organisms representing the orders Ephemoptera (mayflies), Plecoptera (stoneflies), Diptera (flies and midges), and Trichoptera (caddisflies). Nine taxa of mayflies and 10 taxa of stoneflies were present. At site 2 a reduction in the number of taxa representing each order occurred. This change was primarily due to the elimination of both the mayfly and stonefly groups and was indicative of acid drainage (Roback and Richardson, 1969).

At site 2, five genera of mayflies and seven genera of stoneflies were found immediately below the major acid impact area. Of those genera eliminated at site 2, several were found at recovery site 3 and the total number of different organisms representing the two orders were increased to seven and nine. The reduction in the total number of different types of organisms at sites receiving acid leachate has been previously documented (Parsons, 1968; Herricks and Cairns, 1972; and Davis, 1973).

Wet weight and density of organisms were significantly altered. Generally, the highest standing crop occurred at site 1 (range 116 to 1147/m^2 and 174 to 30415 mg/m^2); considerable reductions were observed at sites 2 and 3, (range 54 to 406/m^2 and 25 to 1284 mg/m^2) and (range 11

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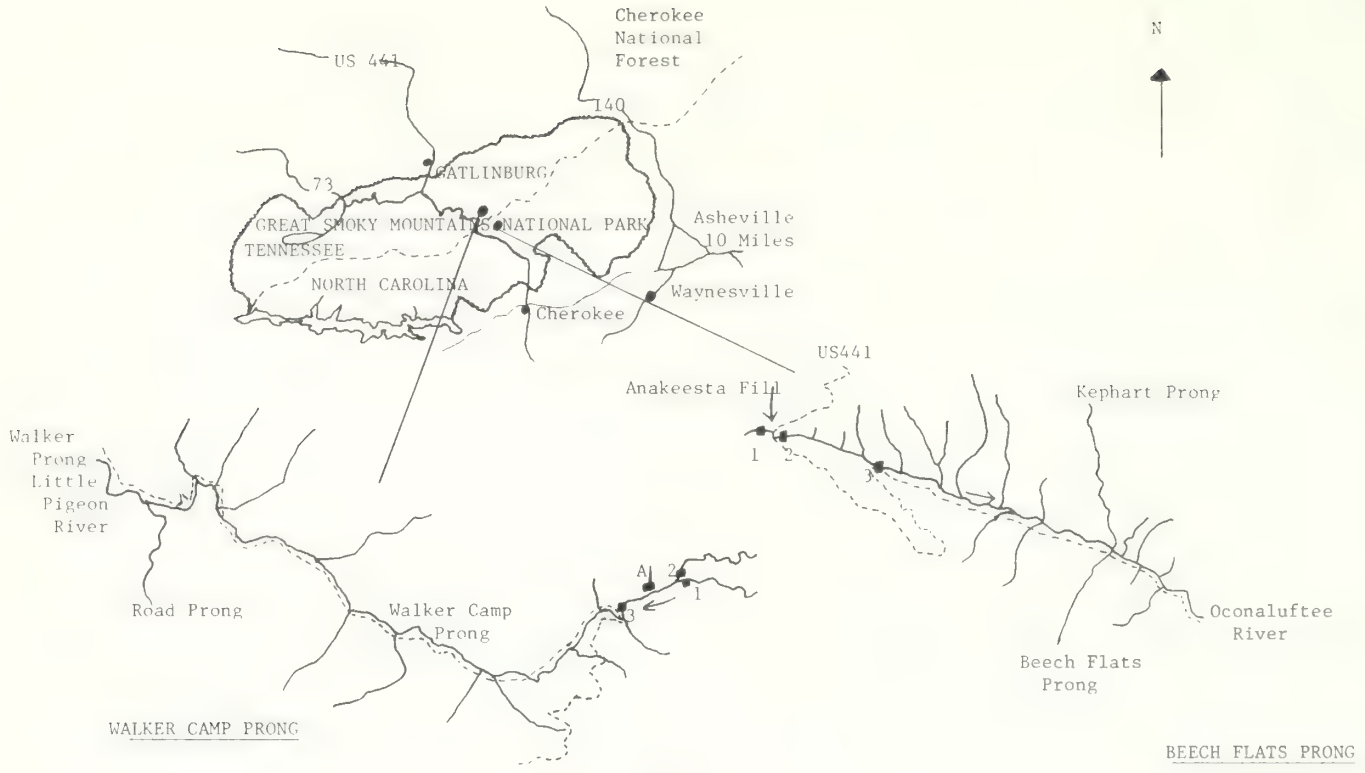

FIGURE 1.

to 606/m^2 and 14 to 3787 mg/m^2), respectively. The noted trend is similar to that found by Davis (1973), who showed that the toxic components of acid mine drainage reduced community density.

Diversity ($\bar{H}$) and evenness (J') values indicated that the community structure at the acid influenced sites was altered. Values for diversity (2.78 to 3.60) and evenness (0.72 to 0.79) at site 1, indicate "clean" water conditions. At site 2, subjected directly to acid leachates, the diversity values were depressed to below 3.00 (1.39 to 2.76) and evenness values were generally less than 0.70 (0.54 to 0.75). Values obtained from samples taken at site 3 typically reflected those at site 2. The reduction in benthic diversity with increasing acid conditions has been previously documented in streams receiving coal mine drainages by Herricks and Cairns (1972); Dills and Rigers (1972).

No significant differences ($P < 0.05$) were found between these community parameters measured at sites 2 and 3, suggesting that no substantial recovery or accommodation in community structure of Beech Flats Prong had occurred at site 3, approximately 2km downstream from the point of acid leachate introduction. These observations correspond with the findings of Koryak et al. (1972), who showed that precipitates formed by neutralization processes in acid mine drainages caused macrobenthic invertebrate communities low in number of taxa, total numbers of organisms, and biomass.

Benthic macroinvertebrate communities of Beech Flats Prong are adversely affected by toxic leachate. No substantial recovery is exhibited, approximately 2 kilometers, below the source. The following detrimental effects to the benthic macroinvertebrate communities were observed: 1) reduction in number of wet weight of organisms per square meter; 2) reduction in number of taxa present; 3) decreased importance of intolerant Ephemeroptera, increased importance of intolerant Plecoptera, and moderately tolerant Diptera and Trichoptera; and 4) decreased diversity ($\bar{H}$) and evenness (J'). These changes indicate stressed benthic macroinvertebrate community structures within leachate receiving regions and support the observation that the Anakeesta leachate is detrimentally altering the aquatic populations of Beech Flats Creek.

Walker Camp Prong

Walker Camp Prong was represented by 40 macroinvertebrate taxa at site 1, a total 35 at site 2, and 30 at site 3. Specific types of organisms found at site 1 and not taken at site 2 and 3 were primarily certain mayflies (Ephemeroptera) and the moderately tolerant forms of caddisflies (Trichoptera). Mayflies commonly occur throughout the study area in Walker Camp Prong owing to the lower contribution of acid leachate relative to Beech Flat Creek.

The density of organisms was somewhat higher at site 2 (189 to 109/m^2) than at either site 1 (17 to 1091/m^2) or site 3 (81 to 1101/m^2). Mean wet weights of organisms was also greater at site 2 (100 to 2284 mg/m^2) than at site 1 (66 to 1608 mg/m^2) or site 3 (99 to 1218 mg/m^2); however, this trend was not significant ($P < 0.05$) or consistent for all sampling periods. The maximum standing crop was obtained at site 3 in June through August. Biomass typically dropped from September and remained low for the remainder of the study at all sites.

Diversity (H) and evenness (J') values at the three sites did not differ significantly. Diversity ranged between 2.00 and 3.00 (0.53 to 3.37 at site 1, 1.33 to 3.20 at site 2, and 1.06 to 3.07 at site 3) and evenness values fell between 0.65 and 0.75 (0.53 to 0.77 at site 1, 0.52 to 0.82 at site 2, and 038 to 0.82 at site 3). These values typically indicate that benthic macroinvertebrate communities of Walkers Camp Prong are seasonally stressed.

Water quality in the right-hand tributary (site 1) was consistently better than at sites 2 and 3; however, the communities at site 1 showed

no significant difference in mean wet weight of organisms per square-meter, diversity or evenness. The number of taxa occurring and dominance of intolerant Ephemeroptera to the community structure in terms of number of species and importance was greater at site 1 than at sites 2 and 3, suggesting the benthic macroinvertebrate communities in this tributary were less stressed in comparison with other sites on Walker Camp Prong.

PHYSICAL ENVIRONMENT

Analysis of stream waters indicates that very narrow and low limits of chemical loading exist. The chemical nature of stream waters within Great Smoky Mountains National Park is characterized by total dissolved solids with levels between 10 ppm and 70 ppm. Within leachate effected stream segments these levels are briefly, as immediate dilution occurs, elevated to between 150 ppm and 250 ppm. Correspondingly pH values which normally range from 6.5 to 7 are depressed to approximately 4.5. Most importantly, aluminum concentrations increase from less than .01 to 6.9 ppm and sulphate from 0.59-132 ppm.

Flows within Beech Flat Creek increase from .03 to .05 cfs, above the area receiving toxic waste loading, to about 2.9 to 3.7 cfs, approximately 2 km below this point. These figures are not indicative of mean, peak or low flows as the streams are not permanently instrumented.

Leachates entering the streams are diluted downstream as flow increases. Below the point of mixing, visible chemical precipitation occurs. Precipitates are periodically redissolved as flows and pH fluctuate seasonally and due to heavy short-term rainfall. Samples of the precipitant have been identified using x-ray techniques as primarily aluminum hydroxide. There was no indication that iron was present in these samples. Narrow limits thus define the chemical regime which must exist to produce this combination of observed by-products.

The following sequence of events observed or inferred from the data is relevant to the occurrence of this rare geochemical event. The often described reaction of water and pyrite results in an insoluble (institute) residue of iron (ferric) hydroxide and a soluble product, sulphuric acid. This reaction goes to completion within the host materials under a highly oxidizing environment and is represented by the following equation:

$$4\,FeS_2 + 10\,H_2O + 15\,O_2 \rightarrow 4HFeO_2 + 16\,H^+ + 8SO_4^{-2}.$$

Immediate dilution, raising pH to levels between five and seven, accounts for iron being totally precipitated as ferric hydroxide rather than being mobilized. At the termination of this reaction a strongly oxiding regime, indicative of high Eh, remains and the continued presence of sulphuric acid and the resulting depressed pH, permits a second reaction involving the hydrolysis of feldspars within the host rock (represented by the albite end member):

$$2\,NaAlSi_3O_8\,(Ab)_c + 2\,H^+ + 9\,H_2O \rightarrow Al_2Si_2O_5\,(OH)_4 + 4\,H_4SiO_4 + 2\,Na^+.$$

Measured "high" aqueous aluminum concentrations at first glance seemingly anomalous are also accounted for because of concurrently elevated sulphate concentrations. Aluminum is postulated to be forming solution complexes with sulphate, thereby, increasing the solubility of aluminum significantly. This mechanism has been verified by (HEM, 1967).

Continuing these conditions, a third reaction follows:

$$Al_2Si_2O_5\,(OH)_4 + 5\,H_2O \cdot 2\,Al(OH)_3 + 2\,H_4SiO_4$$

This reaction has been assigned equilibrium constants from the free energy data and can be observed in the weathering of granite. The end products aluminum hydroxide and silicous acid are mobile within this aqueous system. The resulting zones of precipitation and/or re-resolution of aluminum hydroxide are clearly related to the solubility of aluminum in the presences of sulphate and the variations of pH between five and seven over the affected range of the system.

CONCLUSION

In conclusion, the major results of this study indicate that care must be taken where chemically unstable sulphide enriched zones are encountered during road or other construction projects.

Runoff products from new exposures of sulphide rich rocks may be expected to stress a portion of any nearby water course. Once thought temporary, this study found that biological stress related to acid leachate can last for greater than 10 years for the man-caused event without apparent diminished effect. Evidence also exists that a much broader area than previously expected (up to 24 km) is being affected where flowing water comes into contact with naturally outcropping Anakeesta Formation.

Materials containing sulphide minerals should not be placed in a situation where toxic constituents will freely come in contact with ground or surface waters. When excavated sulphide materials must be disposed of or utilized in suitable areas allowing sufficient stabilization and detoxification of leachates prior to discharge into a water course. These precautions are necessary if managers or planners are to protect against the direct effects of low pH and the here-to-fore little studied toxic and synergistic effects of associated metals, or to forestall the overall chemical alteration of the natural, physical, and biological environment. Recognizing the geochemical regime involved becomes imperative.

Environmental concern over this documented chemical instability of rock materials within the Anakeesta Formation is also consistent with engineering construction considerations that sulphide enriched rock materials do not make good construction fill. Construction costs are increased where efforts are made to reduce environmental damage. Planning costs are also increased when provisions are made for the prior recognition of hazardous materials and for proper engineering prior to construction projects.

The potential threat of mobilized toxic materials at low levels appears to be relevant to other areas subject to variable pH owing to disruptions by man. There is a direct parallel between this occurrence and many existing or potential mining situations. One might want to review, in light of this information, other disturbed areas, especially within the National Park System, to ascertain the ultimate cause and effect of mans activities.

Thus, an indepth geological-hydrological survey should precede all future road and other major construction activities throughout many areas of the National Park System but especially within the sulphide enriched region of the Great Smoky Mountains. Research now underway and in planning stages will better define and delineate the extent of this often subtle threat to park biota. In this manner, the best means of avoiding irreversible damage to natural, scenic, and

recreational resources of exceptional worth will be evaluated.

LITERATURE CITED

BRILLOUIN, L. 1962. Sciences and information theory, 2nd ed. Academic Press, New York, N.Y. 351 pp.

DAVIS, ROBERT M. 1973. Benthic macroinvertebrate and fish populations in Maryland streams influenced by acid mine drainage. Nat. Res. Inst., Univ. Maryland, Contrib. 528. 103 pp.

DILLS, GARY C. and DAVID T. ROGERS, JR. 1972. Aquatic-biotic community structure and an indicator of pollution. Geol. Surv. Ala. Circ. 80. 25 pp.

GREEN, R. L. 1975. Benthic macroinvertebrate communities in Great Smoky Mountains National Park streams influenced by acid drainage. M.S. Thesis. Tennesses Technological University, Cookeville, Tennessee.

HADLEY, JARVIS B. and RICHARD GOLDSMITH. 1963. Geology of the eastern Great Smoky Mountains North Carolina and Tennessee. Geol. Surv. Professional Paper 349-B. 118 pp.

HEM, J. E. 1968. Graphical methods for studies of aqueous aluminum hydroxide, fluoride, and sulphate complexes, United States Geol. Surv. Water Supply Paper, 1827-A. 55 pp.

HERRICKS, EDWIN E. and JOHN CAIRNS, JR. 1972. The recovery of stream macrobenthic communities from the effects of acid mine drainage. Fourth Symp. Coal Mine Drainage Res. Inst. pp. 370-398.

HERRMANN, RAYMOND; JOHN W. HUCKABEE; ROBERT L. GREEN; and ERIC L. MORGAN. 1975. The nature of acid pollution in a small mountain stream, Great Smoky Mountains. GSA, Southeastern Section, 24th Ann. Mtg., p 499, abs.

HUCKABEE, JOHN W.; C. P. GOODYEAR and R. D. JONES. 1975. Acid rock in the Great Smokies: Unanticipated impact of aquatic biota of road construction in regions of sulphide mineralization. Trans. Am. Fish. Soc. 104(4):677-684.

LI, JEROME C. R. 1964. Statistical Inference I. Edward Brothers, Inc., Ann Arbor, Mich. 658 pp.

KING, PHILIP B.; ROBERT B. NEUMAN; and JARVIS B. HADLEY. 1968. Geology of the Great Smoky Mountains National Park, Tennessee and North Carolina. U.S. Geol. Surv. Professional Paper 587. 23 pp.

KORYAK, M; M. A. SHAPIRO; and J. L. SYKORA. 1972. Riffle zoobenthos in stream receiving acid mine drainage. Water Res. 6:1239-1247.

PARSONS, JOHN DAVID. 1968. The effects of acid strip mine effluents on the ecology of a stream. Arch. Hydrobiol. 65(1):25-50.

PIELOU, E. C. 1969. An introduction to mathematical ecology. John Wiley and Sons, Inc., New York, N.Y. 286 pp.

HAVASU CANYON--A NATURAL GEOCHEMICAL LABORATORY

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INTRODUCTION

Havasu Creek, one of the few perennial streams that discharge into the Colorado River within the Grand Canyon, represents a site where the fortuitous combination of water chemistry and valley configuration has enabled us to place realistic limits on the reliability of radiocarbon dates of calcareous tufa, a material whose widespread distribution in areas of the world now quite dry has been interpreted as testimony of once-wetter climates or greater ground-water flux.

THE RADIOCARBON METHOD[3]

Radiocarbon, or radioactive ^{14}C, is produced in the upper atmosphere when low-energy neutrons, continually generated by interaction of cosmic rays with the atmosphere, collide with the nuclei of ^{14}N atoms, displacing a proton from each nucleus so affected. The resulting unstable nuclide, ^{14}C, decays spontaneously to ^{14}N by emission of a β^- particle. The best measurement of the half-life of this decay process is 4,730 $\pm$ 30 calendar years. Equilibrium between rate of production and rate of decay of ^{14}C in the atmosphere is thought to have been established at a concentration of 10^{-12} ^{14}C atoms per stable carbon atom, prior to the artificial enrichment of atmospheric ^{14}C by excess neutrons released in atmospheric nuclear-bomb tests since 1945.

Radioactive ^{14}C reacts chemically like the stable C isotopes and is rapidly oxidized to $^{14}CO_2$, which is utilized in plant photosynthesis more or less as if it were one of the lighter, stable carbon isotopes. During the life of a typical plant, continual contact with the atmospheric carbon reservoir by plant respiration maintains a $^{14}C/^{12}C$ ratio in live plant tissue approximately equal to that in the atmosphere; when the plant dies, however, the ^{14}C content diminishes as spontaneous decay continues in the absence of respiration.

Animals that build their tissues from materials ingested as green plants likewise maintain within their bodies a $^{14}C/^{12}C$ ratio equivalent to that of the atmosphere. Since the half-life of ^{14}C is long with respect to the lifetimes of most plants and animals, even predators high in the food chain can be expected to maintain the atmospheric $^{14}C/^{12}C$ ratio in their tissues. As in plants, however, contact with the atmosphere, however indirect, is broken at the death of an animal, after which radioactive decay proceeds without replenishment of ^{14}C via the food chain.

If it can be assumed that (1) the atmospheric $^{14}C/^{12}C$ ratio has been approximately constant for the last 45,000 years, and (2) that carbon has not been added to or removed from a given sample after its death, then it follows that determination of the $^{14}C/^{12}C$ ratio within the dead organism and comparison of that ratio to the assumed atmospheric ratio will lead to a determination of the time that has elapsed since death of the organism, given the accuracy of the measured half-life.

Radiocarbon concentrations below that remaining after 7 or 8 half-lives are below the limit of detection of contemporary instrumentation. Thus, applicability of this dating method at the present time is effectively limited to the last 45,000 years.

In addition to the straightforward organic pathways described above, students of radiocarbon are interested in mechanisms that fix atmospheric carbon directly in geologic materials without involving the biosphere. For example, rain falling through the atmosphere dissolves CO_2 according to the equation:

$$CO_2 + H_2O \rightleftarrows H_2CO_3 \rightleftarrows H^+ + HCO_3^- \qquad (1)$$

Rain that falls on the Earth's surface may evaporate, may flow directly to the ocean as surface runoff, or may infiltrate through the soil zone to become part of the ground-water system. In passing through the organic litter on the soil surface, CO_2 generated by oxidation of that litter is dissolved according to equation (1); since soil air may contain as much as 100 times more CO_2 than does the atmosphere, most of the HCO_3^- in ground water is derived from the soil.

If such water should emerge from the subsurface as a spring and lose excess CO_2 the relatively undersaturated atmosphere, HCO_3^- may combine with dissolved Ca^{++}, present in abundance in virtually all ground water, to form a precipitate ($CaCO_3$) whose radiocarbon age is approximately equal to the residence time of the water in the subsurface, if the age of the leaf litter is assumed to be small:

$$Ca^{++} + 2HCO_3^- \rightarrow CaCO_{3(ppt)} + H_2O + CO_{2(gas)} \qquad (2)$$

If a ground-water parcel should encounter limestone bedrock, the H^+ ion provided by dissociation of H_2CO_3 will bring about dissolution of $CaCO_3$:

$$CaCO_3 + H^+ \rightleftarrows Ca^{++} + HCO_3^- \qquad (3)$$

Such HCO_3^- will have no measurable ^{14}C if the limestone is older than 45,000 years.

If such a water sample should emerge at the ground surface and release CO_2 to the relatively undersaturated superjacent atmosphere, the reaction of equation (2) will occur, and $CaCO_3$ will be precipitated that owes its C to the atmosphere, the soil zone, and all limestones it may have encountered during subsurface flow. The radiocarbon age of the resultant $CaCO_3$ will be something between 0 (the age of atmospheric carbon) and infinity (the age of the limestone), not an encouraging range of values to the geologist who might try to establish the time of precipitation, or to the hydrologist bent on establishing ground-water flow rates. In exceptional cases, very young water samples may retain enough artificially enriched atmospheric carbon to yield "ages" something less than 0!

Despite this discouraging assessment of the potential problems of using inorganically precipitated fresh-water carbonate materials for radio-

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[3]For a more comprehensive discussion of the geophysics of radiocarbon than will be presented here, see Ralph 1971.

carbon dates, many geologists choose to date inorganic carbonate samples in the absence of more reliable organic material.

We have identified Havasu Canyon, Arizona, as a natural laboratory in which to test empirically the extent of departure of carbonate ages from true ages of precipitation.

HAVASU CANYON, ARIZONA

Havasu Creek, Arizona, rises from perennial springs on the floor of Havasu Canyon and falls 1,470 feet in 10 miles of flow to the Colorado River; the five major waterfalls on the map and on the accompanying long profile (Figure 1) account for approximately 420 feet of this descent.

The spring water emerges from alluvium overlying the Lower Slope Member of the Supai Formation (E.D. McKee, pers. comm. 1973). The creek flows through the underlying Redwall and Temple Butte Limestones, and enters the Colorado River in the upper part of the Muav Limestone (E.D. McKee, pers. comm. 1973; see also McKee 1969; McKee and Gutschick 1969; McKee and Resser 1945; see also Figure 2).

The Havasu Springs represent the discharge point of the Coconino Trough, a subsurface watershed that drains $\pm$ 3,500 square miles of northern Arizona (Cooley 1963; see Figure 2). Both temperature ($\sim 20^{o}C$) and discharge of the springs are remarkably constant (see Table 1), unlike those properties of most other permanent water sources that enter the Colorado River in the Grand Canyon (see Johnson and Sanderson 1968, Table 1); this suggests that the residence time of water in the ground, within the C Multiple Aquifer System of Cooley (1963), is long. The approximate mean discharge of 60 cfs represents 0.25"/yr of precipitation over the watershed, about 1/50 of the mean annual precipitation of 12".

Havasu Creek maintains a permanent community of Havasupai Indians, who practice agriculture on alluvium on the canyon floor near the village of Supai, using Havasu Creek water for irrigation.

In Table 2 we present data from a number of chemical analyses of the water.

The water that emerges from the Havasu Springs carries CO_2 in solution far in excess of what would be present if the water were in chemical equilibrium with the atmosphere. As CO_2 is lost (see equation [2]), $CaCO_3$ is first precipitated at loci of microturbulence, such as bed or bank obstructions or even twigs of streamside trees that hang in the water. Precipitation of $CaCO_3$ on such obstructions increases the interference that the obstructions present to streamflow; this enhances local turbulence which leads to accelerated precipitation.[4] Thus, individual tufa structures may grow to considerable size and may come to span the width of the stream as a complex of festooning, anastomosing tufa ridges that support small waterfalls, separated by quiet, deep pools. The first such tufa dam has been constructed near mile 2.5,[5] just below the village of Supai.

Tufa structures are well developed from mile 2.5 to mile 7.2, just below Beaver Falls. This central length includes the five major waterfalls (see Figure 1), all of which cascade over scarps composed entirely of tufa; it is clear that each waterfall has occupied a series of positions along the scarp in recent years (see discussion in James 1900; Wampler 1959; also compare photographs in the two books).

The tufa geometry we have discussed here is not permanent. Individual structures are in a constant state of change, under normal circumstances the result of continual minor diversion of the stream as some tufa structures grow faster than others. Wholesale modification of tufa morphology occurs whenever heavy local rainfall generates surface runoff in the canyon watershed. Water from such floods typically is undersaturated with respect to $CaCO_3$. Thus, tufa structures may be both dissolved in part and mechanically damaged by the force of water during a flood. A major flood in August 1954 dramatically modified tufa morphology in the central reach of the creek (Black 1955); other floods in historic time have altered the forms of Supai, Navajo, Havasu, and Beaver Falls (James 1900; Iliff 1954; Wampler 1959).

Modification of the course of Havasu Creek, either gradually or catastrophically, results in the drowning of streamside trees. Many of these eventually topple into the creek, where they sink to the bottom of ooze-floored pools or float downstream, to become logged in developing tufa structures. The floors of many pools are covered with a tangle of intertwined, waterlogged branches. Many dams fairly bristle with wood fragments; to a first approximation, those lowest in the wall of a given dam are the oldest.

During June 1969 we collected samples of modern tufa-encrusted wood at frequent intervals along the stream (see figure 3). We assumed that the time that intervenes between the death of a tree in Havasu Canyon and the incorporation of a piece of its wood in a growing tufa dam is not long; thus the first layer of $CaCO_3$ that is precipitated on the surface of the wood should have the same ^{14}C age as the wood itself. If we should find that there is a significant difference between ^{14}C age of the wood and the ^{14}C age of the first layer of tufa, that difference is a measure of the C-isotope disequilibrium between the stream water, from which the tufa precipitated, and the atmosphere, from which the wood C is derived, at the point in the stream where precipitation began and at the time the tree died.

GEOCHEMICAL DATA

We have measured radiocarbon activity in 9 sample pairs,[6] chosen to avoid very young samples that might have been contaminated by bomb carbon; these measurements are recorded in Table 3. The disequilibrium values in column 6 of table 3 were obtained by subtracting the wood age from the tufa age for each sample pair. Each such value is an expression of the magnitude of the C-isotope dis-

[4] A direct chemical precipitation of $CaCO_3$ from fresh water is called tufa while it is still soft; recrystallization of such a sediment, typically after emergence, results in a more durable sediment known as travertine (e.g., see Pettijohn 1957).

[5] The map and long profile of Figure 1 are marked at half-mile intervals. The origin, point 0.0, is a short distance above the present location of the springs and exactly 10 miles, measured along the sinuous course of Havasu Creek on USGS 15' quadrangles Supai, Ariz. (1962), Kanab Point, Ariz. (1962), and Tuckup Canyon, Ariz. (1962), from the mouth of Havasu Creek at the Colorado River.

[6] Two such pairs, from miles 9.53 and 9.70, are from samples of tufa-encrusted wood lying on the stream bank in the lower reach of the creek. Field evidence suggested that these samples had been transported after precipitation began. Disequilibrium values obtained from these two samples are represented by open circles on the plot of Figure 4. The departure from the trend of one of these values supports the interpretation that that sample at least, was transported and redeposited.

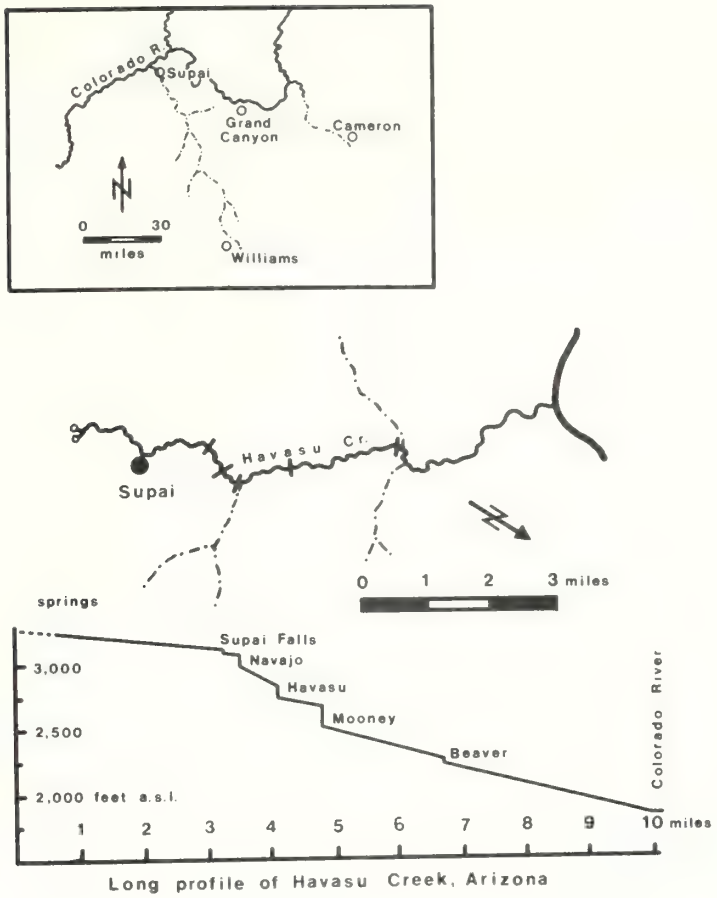

FIGURE 1. Map and long profile of Havasu Creek, Arizona.

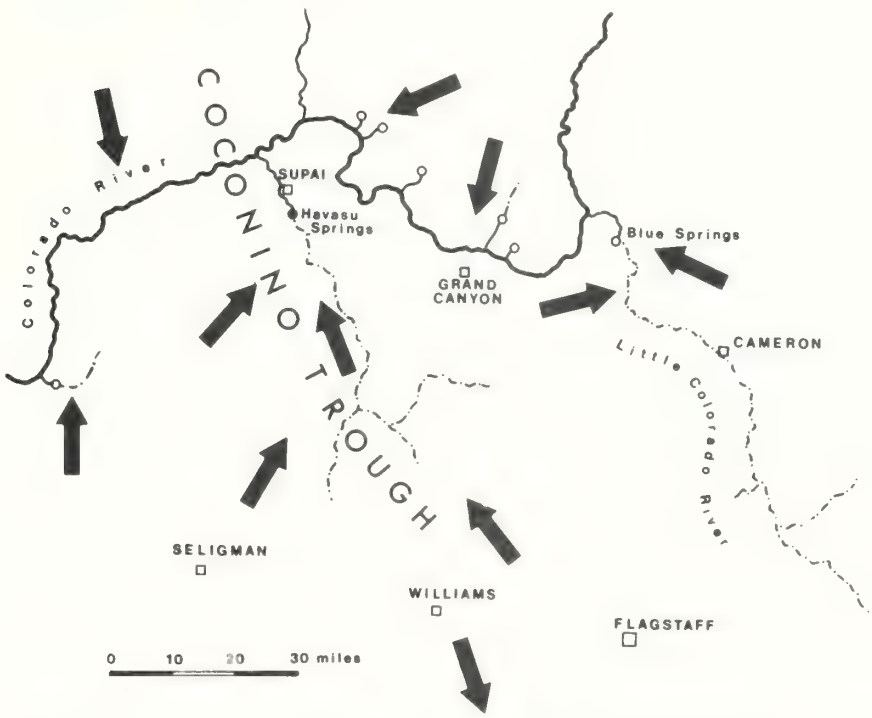

FIGURE 2. Subsurface watershed of Havasu Springs, Arizona. Solid circle ia Havasu Springs; other springs are represented by open circles. Arrows indicate general direction of flow of subsurface water.

TABLE 1. Discharge measurements of Havasu Creek, Arizona.

Date measured	Sample locality	Discharge (cfs)	Source of data	Remarks
9/13/23	mouth	74.5	1	may include local surface runoff
5/20/50	mouth	60.0	1	
10/20/50	mouth	63.8	1	
6/14/51	mouth	59.3	1	
6/16/51	mouth	63.3	1	
6/17/51	mile 0.8	59.3	2	
6/12/52	mouth	62.9	1	
6/13/52	mouth	65.7	1	
6/01/54	∿mile 5.0	61.5	3	
6/12/54	∿mile 1.0	63.3	3	
4/06/65	mouth	66.5	1	
6/25/65	mouth	60.0	1	estimate
8/07/65	mile 0.8	59.5	4	
11/12/67	milw 0.8	61.8	4	
6/29/68	mile 1.3	49.8	4	
6/29/68	mile 4.7	49.6	4	
8/23/68	mile 4.7	53.7	4	
8/23/68	∿mile 1.0	60.4	4	
12/28/68	∿mile 1.0	66.6	4	

Sources:
1. Johnson and Sanderson, 1968, table 1, p. 11.
2. ibid., table 2, p 13.
3. Wampler, 1959, p 12.
4. Measurements by personnel of the U.S. Geological Survey. Provided by E. H. McGavock, Subdistrict Chief, Water-Resources Division, U.S. Geological Survey, Flagstaff, Arizona.

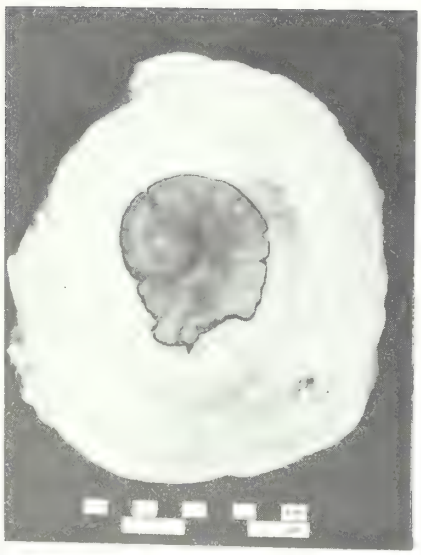

FIGURE 3. A typical section through a tufa-encrusted wood sample.

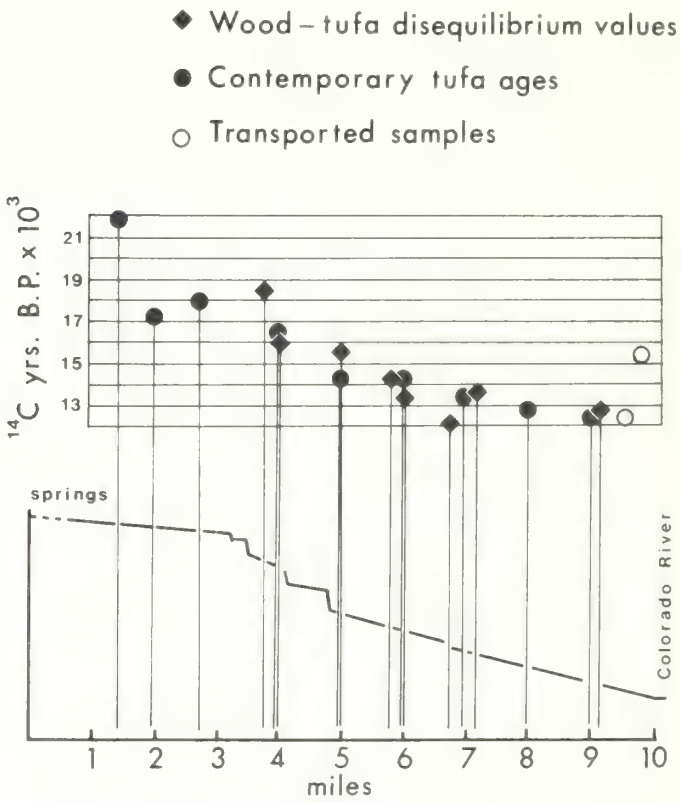

FIGURE 4. Plot of wood-tufa disequilibrium values and contemporary-tufa ages against the long profile of Havasu Creek.

TABLE 2. Chemical analysis of water from Havasu Creek. Except where otherwise noted, concentrations are expressed as milligrams/liter (mg/l) or parts per million (ppm); in dilute solutions, the units are essentially identical.

SAMPLE LOCATION	Date of collection	Temperature °C	Ca	Mg	Na + K	HCO_3	CO_3	SO_4	Cl	F	NO_3	SiO_2	Dissolved solids, mg/l, calculated	Dissolved solids, residue on evap.	Hardness as $CaCO_3$		Percent Na	Na-absorption ratio	Specific conductance (micromhos at 25°C)	pH	Source of data	Remarks
															Ca, Mg	non-CO_3						
∿ mile 8.0	1924?	-	154	63	3	283	-	90	68	-	-	-	657	705	-	-	-	-	-	-	1	a
mile 1.4	10/20/50	21	133	48	27	588	0	36	48	.2	1.4	-	584	-	530	48	10	-	1,030	-	2	
mile 1.4	6/17/51	22	-	-	-	574	0	-	46	-	-	-	-	-	-	-	-	-	1,000	-	2	
mile 1.4	8/7/65	-	74	45	36	416	0	36	48	.2	-	-	-	444	368	27	-	-	820	7.7	2	
mile 3.6	6/16/51	-	-	-	-	384	0	-	47	-	-	-	-	-	-	-	-	-	752	-	2	
Spring mile 4.9	6/16/51	22	109	47	36	526	0	44	48	0	0	-	543	-	466	34	15	.7	959	-	2	b
∿ mile 7.0	6/16/51	21	52	47	28	338	tr	38	48	0	.3	-	380	-	323	46	16	.7	704	-	2	
mile 9.9	6/16/51	21	-	-	-	304	tr	-	48	-	-	-	-	-	-	-	-	-	661	-	2	
mile 0.8	8/7/65		74	45	36	416	0	36	48	.2	-	-	-	-	368	27	-	-	820	7.7	3	
mile 0.6	12/28/66	21	118	45	33	542	0	38	46	.3	-	18	565		478	34	-	-	973	7.7	3	
mile 0.8	11/12/67	21	125	32	40	523	0	40	45	.2	-	18	558	-	446	18	-	-	961	7.4	3	
mile 1.3	6/29/68	20	134	43	42	602	0	38	50	.3	-	20	623	-	512	18	-	-	1,050	7.2	3	
∿ mile 2.0 irr. ditch	6/29/68	-	134	44	39	600	0	35	50	.3	-	20	618	-	514	22	-	-	1,040	7.4	3	c
mile 4.8	6/29/68	21	78	44	39	428	0	38	49	.3	-	24	483	-	376	26	-	-	837	7.7	3	
∿ mile 1.0	8/23/68	-	132	44	46	600	0	35	58	.3	-	25	636	-	510	18	-	-	1,050	7.5	3	
mile 4.8	8/23/68	-	78	44	41	436	0	36	48	.3	-	23	485	-	374	16	-	-	836	7.8	3	

Sources: 1) Wampler, 19. , p. 12. 2) Johnson and Sanderson, 1968, table 2, p. 13. 3) Analyses by personnel of the U.S. Geological Survey. Provided by E.H. McGavock, Subdistrict Chief, Water-Resources Division, U.S. Geological Survey, Flagstaff, Arizona

Remarks: a) Date of collection unknown; analysis reported 12/10/24. Concentrations converted from citation as grains/gallon. HCO_3^- reported as $CaCO_3$ and $MgCO_3$. b) Sample collected from spring inflow below Mooney Falls. c) Sample collected from irrigation ditch; water flows to ditch directly from Havasu Creek.

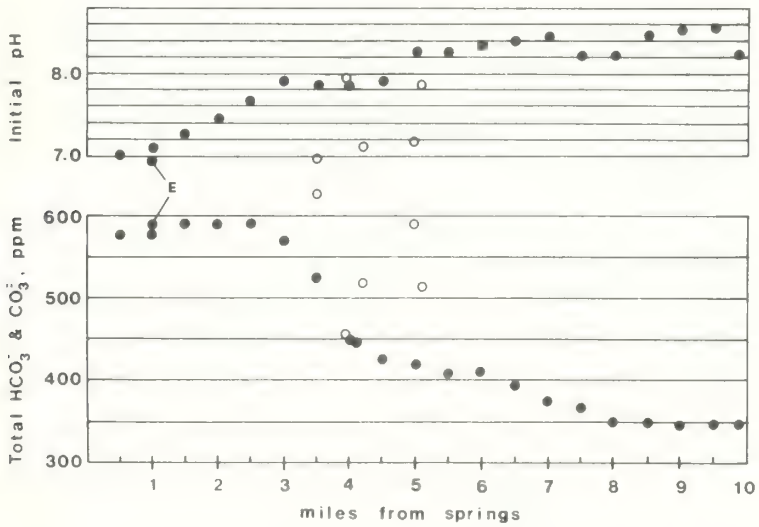

FIGURE 5. Results of in situ titration of water of Havasu Creek and of springs entering the stream. Solid circles represent titrations of stream waters; open circles represent titrations of water from springs entering Havasu Creek. The two points labeled E are from the East Branch of Havasu Creek near the springs; other points from the same mile position are from the West, or main Branch, of Havasu Creek. Se text for fuller description.

TABLE 3. Radiocarbon data list.

PENN Lab No.	Field sample No.	Corrected mile post	Material	^{14}C age (5568)*	Wood-tufa disequilibrium value	Direct disequilibrium value	Remarks
WOOD-TUFA SAMPLE PAIRS							
P-2167	69HC 6.30 TW2	3.70	wood	modern	19,720		
P-2166	69HC 6.30 TW2	3.70	tufa	19,720 ± 300			
P-1632	69HC 5.97 TW1	4.03	wood	137 ± 42	17,010		
P-1642	69HC 5.97 TW1	4.03	tufa	17,010 ± 570			
P-1987	69HC 5.00 TW1	5.00	wood	<20			
P-2044	69HC 5.00 TW1	5.00	wood	<20	16,090		run twice
P-1988	69HC 5.00 TW1	5.00	tufa	16,105 ± 176			
P-1899	69HC 4.25 TW1	5.75	wood	216 ± 46	14,820		
P-1898	69HC 4.25 TW1	5.75	tufa	15,040 ± 250			
P-1897	69HC 4.00 TW1	6.00	wood	436 ± 40	14,140		
P-1896	69HC 4.00 TW1	6.00	tufa	14,590 ± 210			
P-1694	69HC 3.27 TW1	6.73	wood	567 ± 56	12,510		
P-1695	69HC 3.27 TW1	6.73	tufa	13,080 ± 190			
P-2254	74HC 0.87 TW1	9.13	wood	modern	13,680		
P-2255	74HC 0.87 TW1	9.13	tufa	13,680 ± 250			
P-1631	69HC 0.47 TW1	9.53	wood	196 ± 48	12,830		redeposited?
P-1641	69HC 0.47 TW1	9.53	tufa	13,030 ± 300			redeposited?
P-2037	69HC 0.30 TW1	9.70	wood	440 ± 40	16,160		redeposited
P-2038	69HC 0.30 TW1	9.70	tufa	16,390 ± 230			redeposited
CONTEMPORARY-TUFA AGES							
P-2252	74HC 8.60 CT	1.40	tufa	22,850 ± 550		22,850	
P-2251	74HC 8.00 CT	2.00	tufa	18,110 ± 250		18,110	
P-2329	74HC 7.30 CT2	2.70	tufa	19,030 ± 260		19,030	
P-2318	74HC 6.00 CT	4.00	tufa	17,460 ± 260		17,460	
P-2239	74HC 5.00 CT	5.00	tufa	15,370 ± 180		15,370	
P-2319	74HC 4.00 CT	6.00	tufa	15,430 ± 180		15,430	
P-2320	74HC 3.00 CT	7.00	tufa	14,452 ± 180		14,450	
P-2321	74HC 2.00 CT	8.00	tufa	13,790 ± 170		13,790	
P-2322	74HC 1.00 CT	9.00	tufa	13,490 ± 170		13,490	
WOOD-STRATIGRAPHIC AGES							
P-2211	74HC 3.29 OW1	6.71	wood	3,170 ± 50			
P-2212	74HC 6.149 OW1	3.851	wood	modern			
P-2213	74HC 5.80 OW1	4.20	wood	1,670 ± 50			
P-2214	74HC 6.00 OW1	4.00	wood	250 ± 40			
P-2215	74HC METOF OW1	5.21	wood	480 ± 50			
P-2216	74HC 3.60 OTW2	6.40	wood	920 ± 50			
P-2217	74HC 3.60 OW1	6.40	wood	740 ± 40			
P-2218	74HC 5.85 OW1	4.15	wood	130 ± 50			

*Many laboratories choose to retain the half-life value on which many thousands of ages were based in the early days of the method. To convert ages referred to the 5,568 half-life to citation with respect to the 5,730 half-life, multiply the former by 1.04

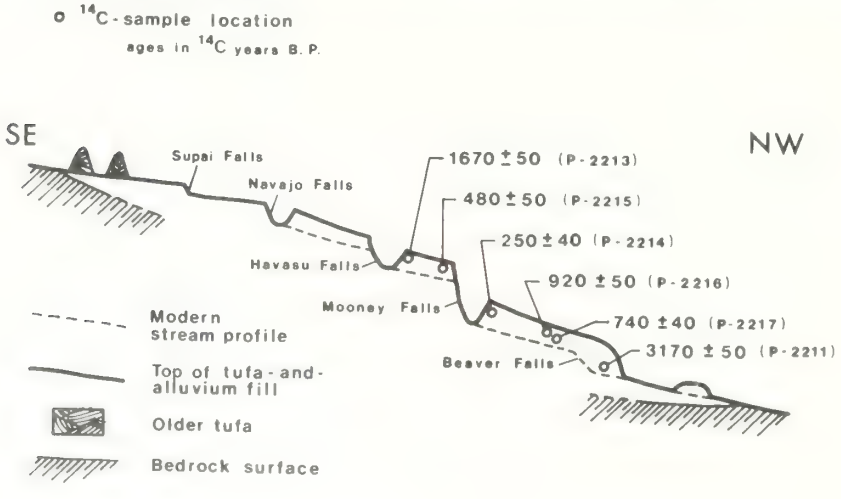

FIGURE 6. Schematic long profile of Havasu Creek, showing distribution of ^{14}C ages of alluvial fill and older tufa. All ^{14}C samples represented here are of wood.

equilibrium between the creek water and the atmosphere at the site where precipitation began and at the time the tree died. These disequilibrium values are plotted on the long profile of Havasu Creek in Figure 4. From this plot it is clear that the difference between the tufa age and the wood age decreases systematically with distance downstream. This trend represents gradual equilibration of the C-isitope spectrum of HCO_3^- in the water with that of CO_2 in the atmosphere as a result of gaseous exchange across the air-water interface; this exchange is probably most effective under conditions of severe turbulence.

In June 1974 we attempted to precipitate $SrCO_3$ directly from stream water to establish an equilibrium curve controlled by ^{14}C activity in the modern atmosphere, but we were unable to exclude from the vessels in which precipitation was to take place fine detrital particles of $CaCO_3$ carried in suspension in the water. Instead, we collected, at half-mile intervals, samples of $CaCO_3$ precipitated on stream-bank moss and on cottonwood leaves suspended in the water; we reasoned that the samples were safely young if chlorophyll was still preserved within the calcite encrustations.

Radiocarbon ages of such contemporary-tufa samples are also listed in Table 3 and plotted on Figure 4. The congruence of the two equilibration curves, well within the range of the standard radiocarbon-age error, is surprising, inasmuch as the C-isotope spectrum represented by the calcite of the contemporary tufa is equilibrating with an atmosphere whose concentration of ^{14}C is roughly 60% greater than the concentration in the atmosphere with which equilibration should have taken place prior to A.D. 1945.

Stable-isotope ratios were determined routinely for all dated samples; corrections based on such measurements would not significantly alter the values of Table 3. Additional stable-isotope ratios are being acquired for selected samples. These data will be reported elsewhere.

In addition to exchange of CO_2 between water and the atmosphere, which the curves of Figure 4 clearly show is occurring, carbon is being lost from the water by precipitation of $CaCO_3$ as tufa, by aquatic photosynthesis, and by degassing of CO_2, the mechanism that triggers precipitation. We undertook a program of titration of the creek water in situ, using the technique developed by Barnes (1964, 1965), to measure the rate of downstream diminution of dissolved carbon species. Titration was accomplished by adding increments of a standard acid to a measured volume of creek water with a micrometer pipette, and monitoring the resulting changes in pH of the samples with a battery-powered pH meter. The equivalence point of each titration was determined graphically from the inflection point of the curve of pH vs. added volume of standard acid. In these waters, the titration alkalinity so determined is a good measure of HCO_3^- concentration (Berner 1971:56).

In Figure 5 we have plotted both initial pH of the sample and the calculated concentration of HCO_3^- against distance downstream; the systematic diminution of total dissolved carbon in the water is apparent.

ALLUVIAL HISTORY

In addition to the modern generation of tufa, Havasu Canyon preserves evidence of a lengthy and probably complex history of deposition of detrital sediment and precipitation of $CaCO_3$. Thick masses of sediment that predate the modern configuration of the long profile of Havasu Creek are preserved near Navajo Falls, just below Havasu and Mooney Falls, and along a half-mile of the canyon above and below the position of the fall now called Beaver Falls. Each of the waterfalls is directly underlain by calcareous tufa, supported by a column of alluvial sediment of unknown thickness. Between the waterfalls the canyon walls are encrusted with benches of crystalline travertine, often many tens of feet above the modern stream bed. No bedrock is exposed in the stream bed above the mouth of Beaver Canyon, at mile 6.7; below this point tufa structures are discontinuous and less well developed. Such sediment may never have been precipitated, either because the total concentration of HCO_3^- is lower here (see Figure 5), or because the reduced gradient of Havasu Creek below Beaver Falls (see Figure 1) minimizes turbulence. Alternatively, surface runoff from Beaver Canyon may have prevented buildup of tufa by removing the sediment as fast as it was precipitated.

The village of Supai itself and the agricultural economy of its inhabitants are built on a broad alluvial fill on the canyon floor.

Wherever natural cuts permit examination of the internal stratigraphy of these deposits, it is clear that the bulk of the sediment consists of alluvial sands, silts, and gravels, derived principally from the Supai Formation, and deposited by running water. Little if any precipitated $CaCO_3$ is present below the top of the column, which is everywhere veneered with a layer of calcareous travertine as much as 6 feet thick. The simplest interpretation of this sequence is that the bulk of the sediment was deposited from water derived from surface runoff during a single alluvial period that was characterized by more abundant rainfall than the area receives today. The tufa veneer was precipitated under conditions like those of today, when the only depositional process of importance is direct chemical precipitation of $CaCO_3$. Recent incision of the combined sedimentary fill has produced the scarps of Navajo, Havasu, and Beaver Falls; historic incision has reduced Beaver Falls to a steep succession of low tufa dams developed on older travertine.

Distribution of older fill along the long profile of Havasu Creek is shown schematically in Figure 6. It is possible from this plot to reconstruct an end-fill profile along the top of the travertine veneer over the sedimentary fill. At the time that such a condition might have prevailed, Navajo Falls would not have existed, Havasu and Mooney Falls would have been much lower than they are today, and Beaver Falls would have been an imposing cataract at the confluence of Beaver Creek with Havasu Creek. Two masses of crystalline travertine protrude above that profile against the east wall of the canyon near Supai Village; presumably they were precipitated during an earlier period of valley alluviation.

Wood fragements are common in the travertine cap that veneers the sedimentary fill, rare within the mass of detrital sediment, and have not been observed in the two masses of older travertine. Enough wood samples have been recovered to impose a broad chronology on the later alluvial history of the canyon. The dated samples appear in the date list of Table 3 and are plotted on the profile of Figure 6.

The oldest date yet acquired from within the alluvial column is 3,170 $\pm$50 ^{14}C years B.P. (P-2211) obtained from the bole of a tree in growth position buried in sandy alluvium at the base of what is now Beaver Falls. We do not know how much alluvium underlies that sample. A wood sample enclosed in the crystalline travertine capping the sedimentary fill at mile 6.40 yielded an age of 920$\pm$50 (P-2216); wood from crystalline travertine precipitated neaby against the alluvial fill during incision yielded an age of 740$\pm$40 (P-2217). Wood samples both from the travertine cap and from tufa dams in the bed of the modern stream give ages

from 0 to 600 ^{14}C years B.P.

We can summarize the late alluvial history as follows: Some time before 3,000 B.P. a mass of alluvium, delivered by surface runoff from the plateau surface, began to accumulate in Havasu Canyon. By 900 B.P. contribution of detrital sediment from that source had ceased, and a thick veneer of $CaCO_3$ was precipitated directly over the alluvium, presumably from water derived from the subsurface. Incision of the tufa-veneered sediment began soon after 900 B.P., and has proceeded at different rates in different parts of the canyon. The present configuration of the long profile of Havasu Creek is rapidly changing as that incision proceeds.

The existence of two masses of crystalline travertine, lacking in wood fragments and extending above the top of the fill deposited during this latest accumulation, suggests that the canyon has experienced more than one such episode of alluviation.

Such deposits are not unique to Havasu Canyon; there are numerous localities within the Grand Canyon where masses of travertine mark the positions of springs that are no longer active.

CONCLUSIONS

The study of carbon-isotope geochemistry and alluvial history of Havasu Creek reported here is not complete, but several major conclusions can already be drawn:

1. Equilibrium of the C-isotope spectrum of HCO_3^- ion in solution in Havasu Creek with the C-isotope spectrum of atmospheric CO_2 is proceeding at least as far as the mouth of the creek; even if we assume a linear equilibration rate and no addition of water below the main complex of springs, approximately 9 additional miles of turbulent flow would be required to bring about total equilibration.

2. Radiocarbon ages of calcareous tufa precipitated at spring orifices or from flowing surface water should not be interpreted as real ages unless limits can be placed on the magnitude of the probable error represented by the C-isotope disequilibrium between the water and the contemporary atmosphere.

3. Havasu Creek has experienced a history of variation in stream regimen. A recent period of alluviation began before 3,000 P.B. and terminated by 900 B.P.; the present time of active incision and rapid and dramatic change of configuration of the creek began before 700 B.P.

We must learn more about the resent history of Havasu Canyon before we attempt to correlate climatic inferences drawn from evidence of variation in stream regimen at this locality with the pattern of recent climatic change described from elsewhere on the Colorado Plateau. Our growing understanding of the mechanisms that control precipitation of calcareous tufa in Havasu Creek may enable us to draw conclusions of paleoclimatic significance from masses of calcareous tufa and travertine that bear witness to periods of greater groundwater flux in other parts of the Grand Canyon.

ACKNOWLEDGEMENTS

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LITERATURE CITED

BARNES, IVAN. 1964. Field measurement of alkalinity and pH. U.S. Geological Survey Water-Supply Paper 1535-H:H1-H17.

_____. 1965. Geochemistry of Birch Creek, Inyo County, California--a travertine depositing creek in an arid climate. Geochim. et Cosmochim. Acta 29:85-112.

BERNER, R. A. 1971. Principles of chemical sedimentology. McGraw-Hill.

BLACK, D. M. 1955. Natural dams of Havasu Canyon, Supai, Arizona. Science 121:611-612.

COOLEY, M. E. 1963. Hydrology of the Plateau Uplands Province. *In* Annual report on ground water in Arizona, Spring 1962 to Spring 1963, by N. D. White, R. S. Stulik, E. K. Morse, and others: Ariz. State Land Dept. Water-Resources Report 15:27-38.

ILIFF, F. G. 1954. People of the blue water. Harper and Bros., New York, 271 p.

JAMES, G. W. 1900. In and around the Grand Canyon. Little, Brown, and Co., Boston, 241 p.

JOHNSON, P. W., and R. B. SANDERSON. 1968. Spring flow into the Colorado River--Lees Ferry to Lake Mead, Arizona. Arizona State Land Department Water-Resources Report No. 34, 26 p.

MCKEE, E. D. 1969. Stratified rocks of the Grand Canyon. U.S. Geological Survey Professional Paper 669:-B:23-58.

MCKEE, E. D., and C. E. RESSER. 1945. Cambrian history of the Grand Canyon Region. Part 1, stratigraphy and ecology of the Grand Canyon Cambrian. Carnegie Inst. Washington Pub. 563: 3-168.

MCKEE, E. D., and R. C. GUTSCHICK. 1969. History of the Redwall Limestone of northern Arizona. Geol. Soc. America Memoir 114, 612 p.

PETTIJOHN, F. J. 1957. Sedimentary rocks. Harper and Bros., New York, 718 p.

RALPH, E. K. 1971. Carbon-14 dating. *In* Dating techniques for the archeologist, coedited by Henry N. Michael amd Elizabeth K. Ralph, MIT Press, p 1-48.

WAMPLER, JOSEPH. 1959. Havasu Canyon--gem of the Grand Canyon. Howell-North Press, Berkeley, California, 121 p.

STRATIGRAPHY AND MICROFOSSILS OF THE PRECAMBRIAN ALTYN FORMATION OF GLACIER NATIONAL PARK, MONTANA[1]

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INTRODUCTION

The history of sedimentation during Late Precambrian times in what is now the northwestern United States and southwestern Canada has been reviewed by Harrison (1972), Gabrielse (1972) and Monger et al. (1972). The sedimentary rocks occur in two distinct stratigraphic units. The oldest of these is the Belt Supergroup (known as Purcell in Canada) which rests unconformably on crystalline basement in some areas. The Belt rocks are overlain unconformably by either sedimentary rocks belonging to a younger Precambrian sequence known as the Windermere Supergroup or by Middle Cambrian Rocks. The Altyn Formation is part of the Belt Supergroup.

GENERAL STRATIGRAPHY OF THE BELT (PURCELL) SUPERGROUP

In discussing the evolution of the Canadian Cordillera Monger et al. (1972) suggest that rifting of a continental plate occurred during the middle Proterozoic. The eastern part of this rifted plate became the North American craton and served as a source area for the Precambrian sediments. They interpret the Purcell (Belt) sequence as a continental shelf:slope:rise assemblage at the western margin of the North American craton. The Purcell sediments show a general increase in thickness from east to west and change from shallow water to deeper water sediments in the same direction. They note also that in the west there is a change from older turbidite sediments in the lower part of the Purcell to shallow water sediments in the upper part. The Purcell sediments are underlain by crystalline basement and generally have isopachs oriented with a northnorthwesterly trend. The Purcell rocks are thus interpreted as a miogeoclinal wedge of sediments deposited on the western margin of the North American craton.

It has been suggested by Stewart (1972) that the Windermere Supergroup sediments represent the initial deposits of the Cordilleran geosyncline which was formed by continental rifting after the deposition of the Belt Supergroup. He believes that the Belt Supergroup rocks and their equivalents were deposited in epicratonic troughs scattered across the North American craton and that marginal miogeoclines did not develop around the craton until continental rifting took place in post-Belt times (Stewart 1976). The possibility of two rifting events one before and one after Belt Supergroup deposition was raised by Burchfiel and Davis (1975), although they say that direct structural evidence for the older rifting is not found. Evidence cited in favor of pre-Belt rifting includes the continental terrace wedge of sediments mentioned above which is believed to have formed at a rifted continental margin and the presence of several Belt age aulacogen-like troughs in the western United States. The interpretation of these troughs as aulacogens implies the existence of a rifted continental margin to the west. Harrison et al. (1974) believe that the Belt basin is one of a number of epicratonic reentrants formed along the western edge of the craton at the eastern margin of the Cordilleran miogeocline. Stewart (1976) suggests that the evidence for the existence of this western ocean and connection to it of Belt age basins is not very strong.

Based on paleomagnetic data Piper (1976) has postulated the existence of a Proterozoic supercontinent. Using this reconstruction Davies and Windley (1976) place the Belt basin on the leading edge of a rotating supercontinent. Irving and McGlynn (1976) have described the paleomagnetism and tectonic evolution of Laurentia. According to their reconstruction the North American craton was rotating in a counter clockwise fashion during the deposition of Belt sediments which would place the Belt basin on the trailing edge of the continent. Monger et al. (1972) believe that the Proterozoic sedimentary wedges accumulated at the trailing margin of the North American craton. Harrison and Reynolds (1976) conclude that during the late Precambrian, tectonism in the western United States was dominated by vertical motion characteristic of a trailing edge which produced grabens approximately perpendicular to the continental margin. Belt age sediments accumulated in these basins and along the continental margin and there was a westward extension of the craton on the south side of the Belt basin. This positive feature, which he names the Salmon River arch, interrupted the continuity of the Cordilleran miogeocline and provided a south and southwest source for the Belt basin sediments. Armstrong believes that his interpretation of the shape of the Belt basin strengthens the idea that it was an aulacogen. Harrison and Reynolds (1976) conclude that the Belt age epicontinental basins were not aulacogens.

THE BELT SUPERGROUP IN GLACIER NATIONAL PARK

The tectonic features of the Belt basin were described by Harrison et al. (1974). They show that the basin was bounded to the northeast by the North American craton and to the south by the faulted Dillon block and Belt island. The latter is approximately equivalent to the Salmon River arch described by Armstrong (1975). They defined some broad tectonic features within the Belt basin which they believe were formed by differential subsidence rather than uplift. A triangular-shaped relative high area, the Purcell platform, occupies the northwest central part of the basin. This is bounded to the northeast by the southeast trending Flathead trough and to the southwest by the eastsoutheast trending Coeur d'Alene trough. These two troughs meet towards the southeast to form the Helena embayment. According to this reconstruction that part of the Belt Supergroup now exposed in Glacier National Park was deposited in or close to the Flathead trough.

Ross (1959) has described the geology of Glacier National Park, most of which is made up of Belt Supergroup rocks, and reviewed earlier geologic studies. Harrison (1972) has provided a synthesis of the geology of the Belt basin and reviewed the more recent work. A simplified stratigraphic

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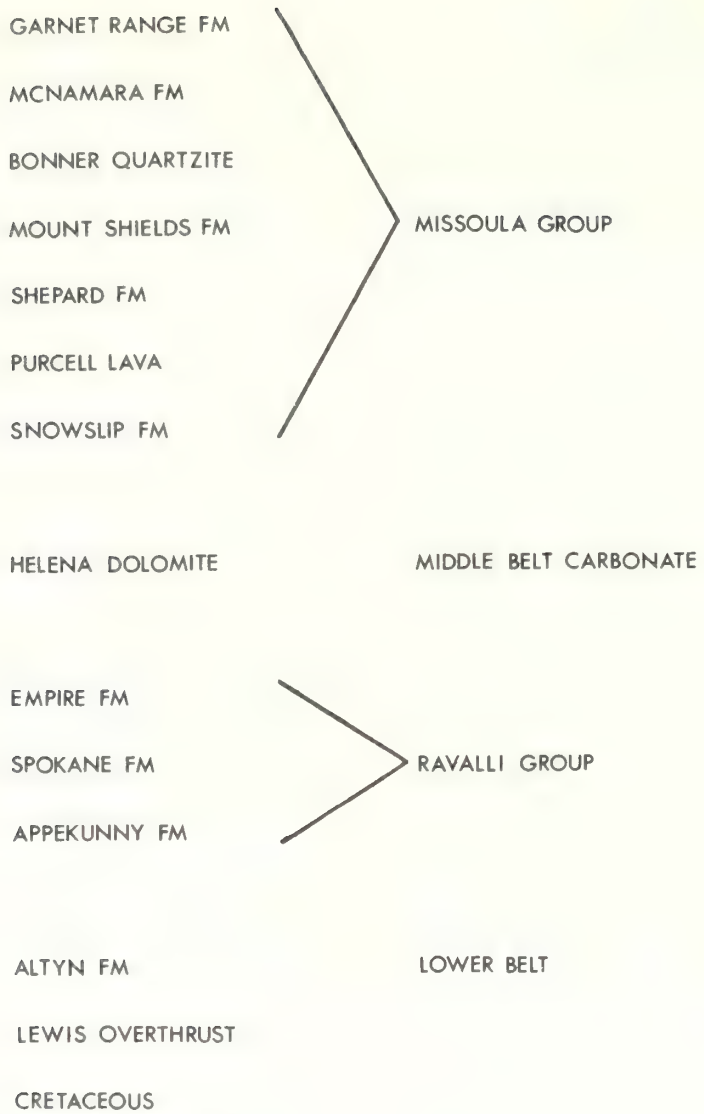

FIGURE 1. Belt supergroup in Glacier National Park and vicinity (mainly after Harrison 1972).

column for the Belt Supergroup in Glacier National Park is shown in Fig. 1 based largely on the terminology recommended by Harrison (1972). In the past the middle Belt carbonate in the park area was called the Siyeh Limestone and the Spokane Formation was known as the Grinnel Formation. At the base of the Belt Supergroup in Glacier National Park the Altyn Formation is thrust over Cretaceous rocks along the Lewis Thrust and the original sedimentary base is unknown.

AGE OF THE ALTYN FORMATION

No radiometric age determinations have been made on the Altyn Formation but some idea of its age can be obtained by considering its stratigraphic relationship to dated parts of the Belt sequence.

In some areas at the eastern margin of the Belt basin Belt Supergroup rocks rest unconformably on crystalline basement rocks. A biotite-hornblende gneiss from beneath the basal Niehart Quartzite of the Belt Supergroup in the Belt Mountains gave K-Ar ages of 1750 m.y. and 1790 m.y. on biotite and hornblende respectively (Burwash et al. 1962). In southwest Montana basement gneisses beneath the lower Belt Lahood Formation gave whole rock ages of 1700±100 m.y. (Giletti 1966). Harrison (1972) suggests that uniform K-Ar dates of around 1740 m.y. from the crystalline basement represent a period of regional uplift prior to deposition of the Belt Supergroup. The maximum possible age for the older Belt Supergroup rocks is therefore around 1700 m.y., at least in the eastern part of the Belt basin where its relationship to the basement is clearer than further west.

A minimum age for the Belt Supergroup is established by a K-Ar age of 760±50 m.y. on biotite from a sill which intrudes the Garnet Range Formation from the uppermost Belt (Obradovich and Peterman 1968). A shale from near the top of the Siyeh (Helena) Formation in Glacier National Park has 2M illite believed to have formed during a metamorphic event. According to Goldich et al. (1959) this has a K-Ar age of 740 m.y. and a Rb-Sr age of 780 m.y. (later recalculated to 740 m.y. by Gulbrandsen et al. 1963). This sets a minimum possible age for the Siyeh (Helena) Formation.

Uraninite from two pitchblende samples which cut the St. Regis Formation (Upper Ravalli Group) gave Pb^{207}/Pb^{206} ages of 1035±35 m.y. and 1190±30 m.y. (Eckelmann and Kulp 1957). Amphibole from a Purcell sill at Logan Pass, Glacier National Park has a K-Ar age of 1110 m.y. (Hunt 1962). Glauconites from the upper Missoula Group gave minimum ages of 1090 m.y. for K-Ar and 1050 m.y. for

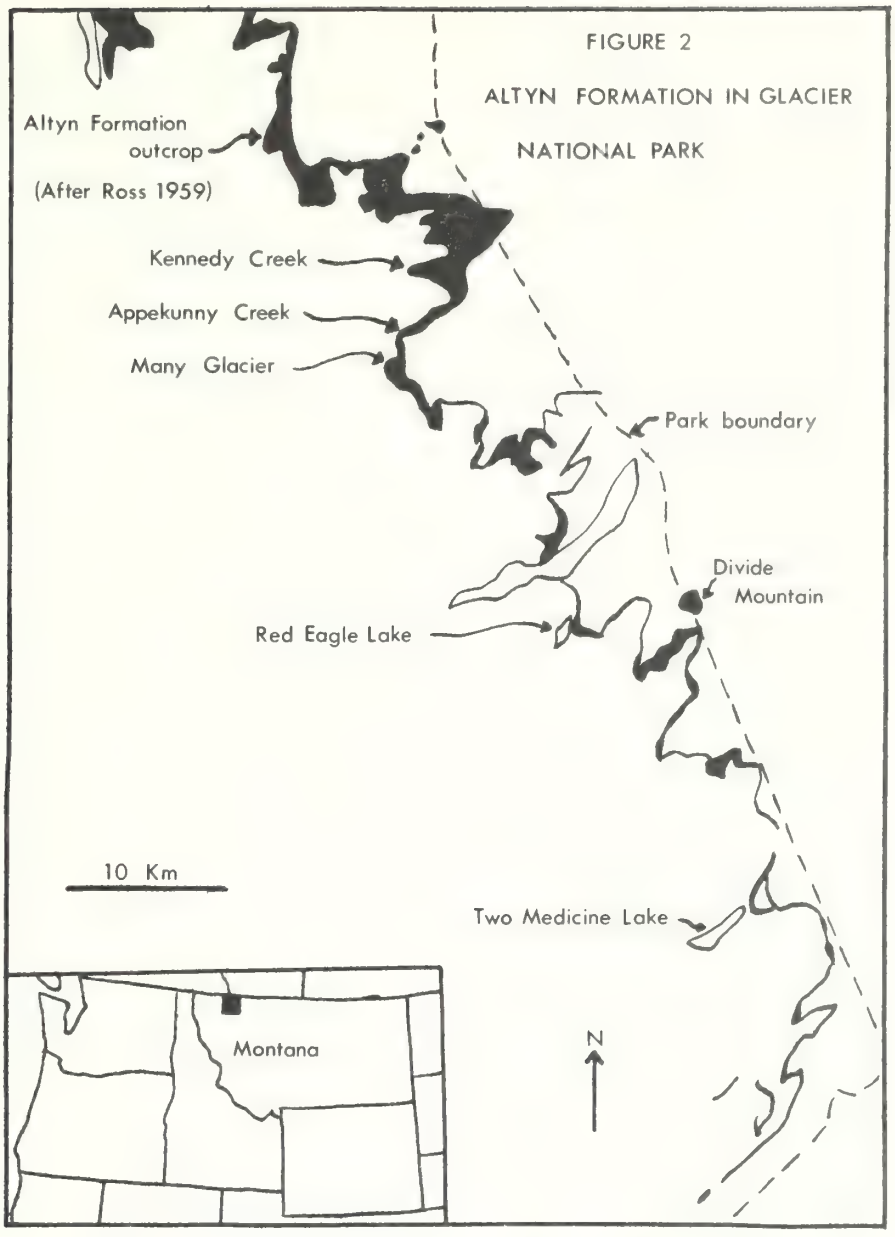

FIGURE 2. Altyn Formation in Glacier National Park.

Rb-Sr (Gulbrandsen et al. 1963). Obradovich and Peterman (1968) gave ages of around 1100 m.y. for a sequence of rocks ranging from the upper part of the Ravalli Group to the middle of the Missoula Group. Harrison (1972) suggested that this isochron is insensitive and the 1100 m.y. age is valid only for the Missoula Group and that the stratigraphically lower rocks may be older. Obradovich and Peterman (1968) determined a K-Ar age of 1330±45 m.y. for a biotite produced by metamorphism of the Prichard Formation. The Prichard Formation belongs to the lower Belt and it is the western equivalent of the Altyn Formation (Harrison 1972). A Rb-Sr whole rock age of 1325±15 m.y. on shales from the lower Belt of the Belt Mountains was determined by Obradovich and Peterman (1968). Armstrong (1975) believes that this is a minimal age for this sequence as the ages may have been modified by a later metamorphic event. Zartman and Stacey (1971) measured lead isotope ages from galena mineralization along faults in rocks mainly from the lower Belt Prichard Formation, but also from the Ravalli Group and the middle Belt Wallace Formation. These have ages ranging from 1200 to 1500 m.y. with a concentration around 1400 m.y.

The Aldridge Formation of British Columbia is equivalent to the Altyn Formation (Price 1964) and together with the middle Belt Kitchener (Siyeh) Formation it is cut by Moyie basic intrusions (Ryan and Blenkinsop 1971). The Aldridge Formation and Moyie intrusions within it are cut by the younger Hellroaring Creek granodiorite stock from which Ryan and Blenkinsop (1971) obtained a Rb-Sr whole rock age of 1260±50 m.y. This was later recalculated to 1335 m.y. by Obradovich and Peterman (1973), which gives a minimum age for the Aldridge Formation. The relationship of the Moyie sills to the granodiorite can be interpreted in two ways. Some clearly are older than the granodiorite which intrudes them but where this relationship is not exposed the sills could be younger. Ryan and Blenkinsop (1971) suggested that there were two phases of intrusion of the Moyie sills, one before and one after the granodiorite intrusion. This interpretation is based on the fact that some of the sills cut the Kitchener (Siyeh) which was believed equivalent to rocks dated at 1050 m.y. by Obradovich and Peterman (1968). As mentioned above Harrison (1972) believed that the 1100 m.y. ages determined by Obradovich and Peterman (1968) for rocks older than Missoula Group

are probably too young. It is thus possible that all the Moyie sills were intruded during one phase and that they and the Kitchener (Siyeh) as well as the Aldridge Formation are more than 1335 m.y. old.

Lead isotope studies of zircons from metamorphosed sediments in Idaho believed to belong to the Prichard Formation give an age of 1490 m.y. for metamorphism of the Prichard Formation (Reid et al. 1973). The geology of this part of Idaho is complex and some geologists suggest that these rocks are pre-Belt in age (Harrison 1973). Zircons from a basic sill which intrudes the middle part of the Prichard Formation in Boundary County, Idaho give an age of 1430 m.y. (Zartman U.S.G.S. unpublished data 1974).

Assuming that correlation with the Prichard and Aldridge formations is correct a minimum age of 1450 to 1500 m.y. seems reasonable for the Altyn Formation. A maximum possible age of about 1700 m.y. is given by age data from the underlying crystalline basement.

The apparent polar wandering path for Laurentia during the Proterozoic is reasonably well established (Irving and McGlynn 1976) and an indication of the age of rocks of known paleomagnetism may be obtained by plotting their position on the path. Evans et al. (1975) have summarized available data and show that the mean paleomagnetic pole for the lower Belt plus Ravalli Group is 148°W 8°S and for Missoula Group rcoks it is 152°W 16°S. These data plot on Track 4A of Irving and McGlynn (1976) and suggest an age for the Belt Supergroup of 1300 to 1475 m.y. (Evans et al. 1975).

Attempts have been made to use stromatolites for stratigraphic subdivision, correlation and dating of Precambrian sedimentary rocks (see Walter 1972 for a comprehensive review). White (1970) identified *Baicalia* from the upper part of the Altyn Formation and suggested an age of 1350 m.y. for the formation. This is the only attempt to directly determine the age of the Altyn Formation known to the author. The validity of stromatolite biostratigraphy has been questioned (Hofmann 1969, 1973, 1975) partly because of the discovery of supposed middle and upper Proterozoic forms in the lower Proterozoic. The presence of *Baicalia* in the Altyn Formation suggests that the stratigraphic range of this stromatolite should be extended backwards in time beyond the lower limit of 1350 m.y. usually assigned to it (Walter 1972).

STRATIGRAPHY OF THE ALTYN FORMATION

The Altyn Formation occurs only in the eastern part of Glacier National Park where it forms a rather narrow outcrop (Fig. 2). A simplified stratigraphic column for the Altyn Formation from the type locality established by Willis (1902) in the Appekunny Creek area is shown in Fig. 3. There is abundant evidence that much of the Altyn Formation was deposited in intertidal and supratidal areas. Shallow subtidal deposition is inferred for some parts of the formation, however, certain identification of such environments is difficult in the absence of a marine fauna in these ancient rocks.

Evidence for periodic subaerial exposure is provided by desiccation cracks at several horizons. Disrupted laminated dolomicrites occur and the intraformational breccias produced by short distance transport of the resulting fragments are very common. Erosion surfaces and channels which are often filled by intraformational breccias are common at some horizons.

Algal mats occur in much of the Altyn Formation and columnar stromatolites are common in the lower part of the formation. Birdseye texture occurs in many of the finer grained rocks. Crossbedding and asymmetrical current ripple marks show bimodal current directions with two prominent directions, one towards and one away from the northeast. This suggests the influence of tidal currents perpendicular to a northwest to southeast trending shoreline. Oscillation ripple marks occur in the lower part of the Altyn Formation in the Appekunny Creek and Many Glacier areas, showing some influence of wave action on the sediments.

Indications of the former presence of evaporite minerals are found at a number of horizons in the Altyn Formation. Vugs of calcite, dolomite and chert are common in places and in some cases they have relict "chicken wire" structure. Chert rosettes occur in dolomicrites in the lower part of the formation. The vugs and rosettes are believed to be replacements after nodular anhydrite and gypsum. Occasional small scale collapse breccias thought to be due to solution of evaporite minerals are further indication of an evaporitic environment. Microscopically chert and dolomite pseudomorphs after gypsum and anhydrite occur as well as length-slow chalcedony which is found as spherulites and rims around various grains. According to Folk and Pittman (1971) length-slow chalcedony is a frequent indicator of evaporitic environments. Although named the Altyn Limestone by Willis (1902) X-ray diffraction analyses and staining of thin sections, peels and polished slabs indicate that almost all of the carbonate material in the Altyn Formation is dolomite. Such pervasive dolomitization requires evaporitic conditions to increase the Mg:Ca ratio of interstitial brines by the precipitation of calcium-rich minerals such as gypsum and anhydrite (Bathurst 1971, 517-543).

All the criteria suggested by Lucia (1972) for the recognition of evaporitic-carbonate shoreline sediments are found in the Altyn Formation except those related to faunal elements which are not applicable to these Precambrian rocks.

The distribution of various sedimentary structures and other features in the Altyn Formation is shown in Fig. 3 and illustrated in Fig. 4. Unit A contains numerous columnar stromatolites which are interbedded and interfinger with finely laminated dolomicrites and sandy dolarenites. The stromatolites frequently occur in channels and they are laterally discontinuous. They commonly are associated with coarse breccias and grew under relatively high energy conditions. Unit B is composed of sandy, peloidal, intraclastic and oolitic dolarenites which form massive cliff-forming rather featureless rocks in the field. Unit C is made up mainly of algal mats interbedded with thin clastic layers containing dolomicrite intraclasts and terrigenous sand. Unit D is a thin but widespread stromatolite unit which contains the branching columnar stromatolite *Baicalia*. Although only 1 to 2 m thick this stromatolite unit has been traced for several kilometers from Kennedy Creek south to Red Eagle Lake. It is absent on Divide Mountain and in the Two Medicine valley. In the Appekunny Creek-Many Glacier area the Altyn Formation ends with Unit E composed of brown-weathering sandy dolarenites with common crossbedding and coarse terrigenous sand. The Altyn Formation passes upward into the overlying non-carbonate Appekunny Formation with no sign of a break in sedimentation. Units D and E are absent from Divide Mountain and areas further south and the Altyn Formation passes conformably upward from Unit C into the overlying Appekunny Formation.

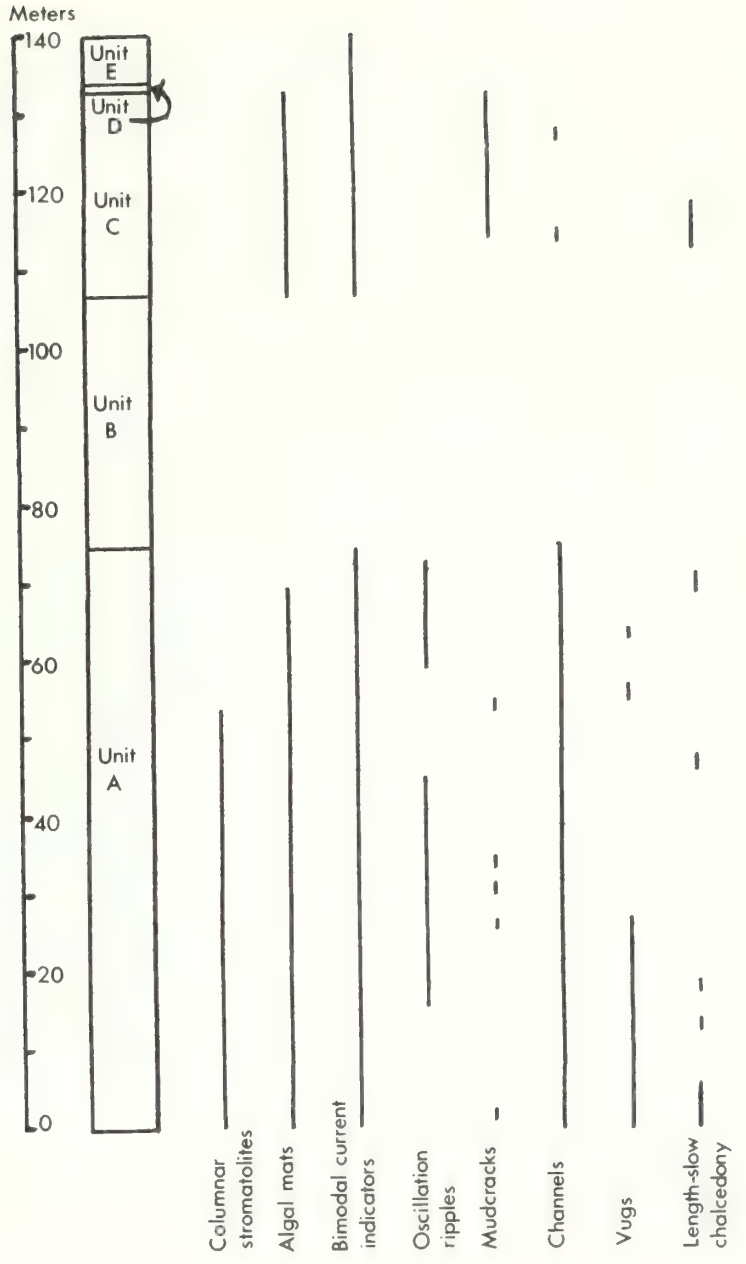

FIGURE 3. Altyn formation type section Appekunny Creek, Glacier National Park.

The Altyn Formation sequence represents an overall regression from an evaporitic carbonate shoreline environment to the overlying non-marine Appekunny Formation which contains red beds in some parts. In the lower part there are tidal flat sediments with finer sediments cut by numerous tidal channels in which coarse intraclasts and terrigenous sands accumulated and columnar stromatolites grew under the influence of tidal currents. Sandy dolarenites with quartz and microcline grains and lithoclasts of granite together with peloids, intraclasts and ooids occur as layers of variable thickness and lateral continuity. These dolarenites are common in the middle part of the Altyn Formation at Appekunny Creek and in the lower and middle parts on Divide Mountain where they are interbedded and interfinger with columnar stromatolites. These rocks probably represent beach deposits and shallow subtidal shelf sands although specific identification is often difficult in the absence of faunal remains and the scarcity of sedimentary structures. Unit C represents a very widespread unit deposited in the supratidal zone which brings the Altyn Formation to an end in some areas. In the Appekunny Creek and adjacent areas, however, there is a widespread but thin stromatolite unit which probably represents a minor transgressive event. This is overlain by sandy dolarenites thought to be beach sands which pass upward into the overlying Appekunny Formation.

The evaporitic tidal flat sediments, dolomitization and abundant algal stromatolites found in the Altyn Formation suggest a warm, rather arid climate similar to the present day Arabian Gulf (Schneider 1975, Bathurst 1971, p. 178-212). This interpretation is in accord with what is known of the paleolatitudes for the Belt Supergroup. Paleomagnetic data from the Waterton Formation of

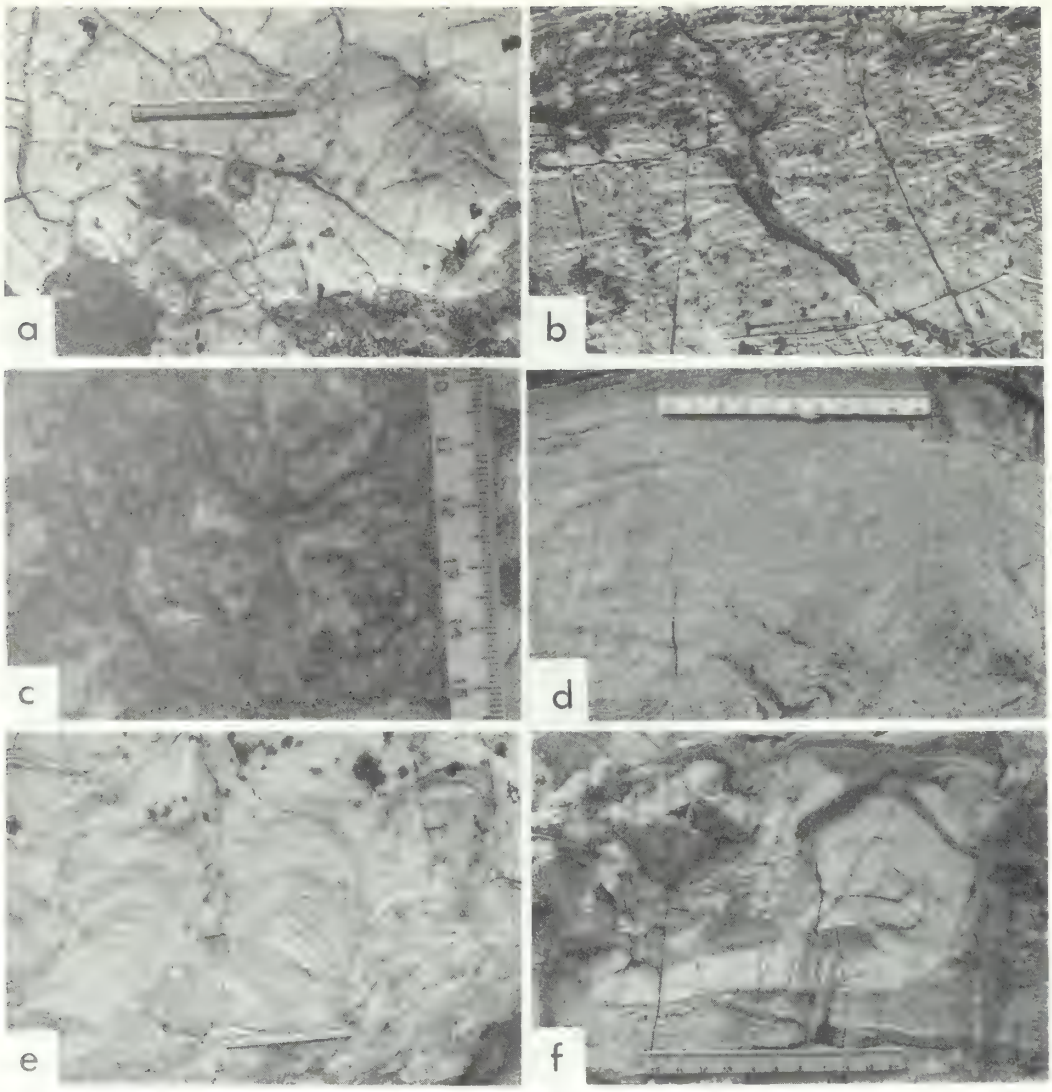

FIGURE 4. Sedimentary and organosedimentary features from the Altyn Formation, Glacier National Park. a. Desiccation cracks, Unit C Appekunny Creek. b. Intraformational breccia produced by desiccation and disruption of laminated dolomicrite. Unit C. Near St. Mary Lake. Scale in inches. c. Vug of calcite, dolomite and quartz formed by replacement of "chicken wire" anhydrite. Unit A. Appenkunny Creek. d. Contorted algal mats. Unit C. Appekunny Creek. e. Columnar stromatolites. Unit A. Appenkunny Creek. f. Columnar stromatolite which grew on and among coarse breccia in a tidal creek. Unit A. Appekunny Creek. Scale for a and c-f is in cm.

southern Alberta, which is equivalent to or slightly older than the lower Altyn Formation, show a paleomagnetic polar position of 137.5°W 20°S (Black 1963). Similar data from the Appekunny Formation of Glacier National Park, which immediately overlies the Altyn Formation, show a paleomagnetic pole at 156°W 15°S (Collinson and Runcorn 1960). Calculations using these data and the method described by Haile (1975) show that the Waterton Formation was deposited at about 18°N and the Appekunny Formation at 16°N. Thus the Altyn Formation must have been deposited in latitudes 16° to 18°N under tropical conditions which would favor high evaporation rates on emergent tidal flats. Evidence for former life in the Altyn Formation.

The existence of living organisms during the deposition of a sedimentary unit may be manifested in a number of ways. The activities of animals or plants may produce a characteristic trace which can be fossilized and prove their former presence even when the actual animal or plant is not preserved in the sedimentary record. The lack of disturbance of finely laminated marine sedimentary rocks from the lower Belt Supergroup in the Helena area was interpreted by Byers (1976) as evidence that the burrowing metazoans had not yet evolved by lower Belt time. Similar finely laminated rocks in the Altyn Formation have thus far yielded no evidence of bioturbation thus further supporting the idea that lower Belt sediments were deposited in the absence of burrowing metazoans.

Studies by numerous authors of modern stromatolites show that an essential requirement for their formation is the presence of microorganisms, especially blue-green algae (see Bathurst 1971, 217-230 for a review). The discovery of stromatolites in ancient sedimentary rocks is thus proof of the existence of such microorganisms at the time of deposition even in the absence of fossil microorganisms. The abundant stromatolites in the Altyn Formation thus provide evidence for a flourishing microbiota at the time of deposition of the formation.

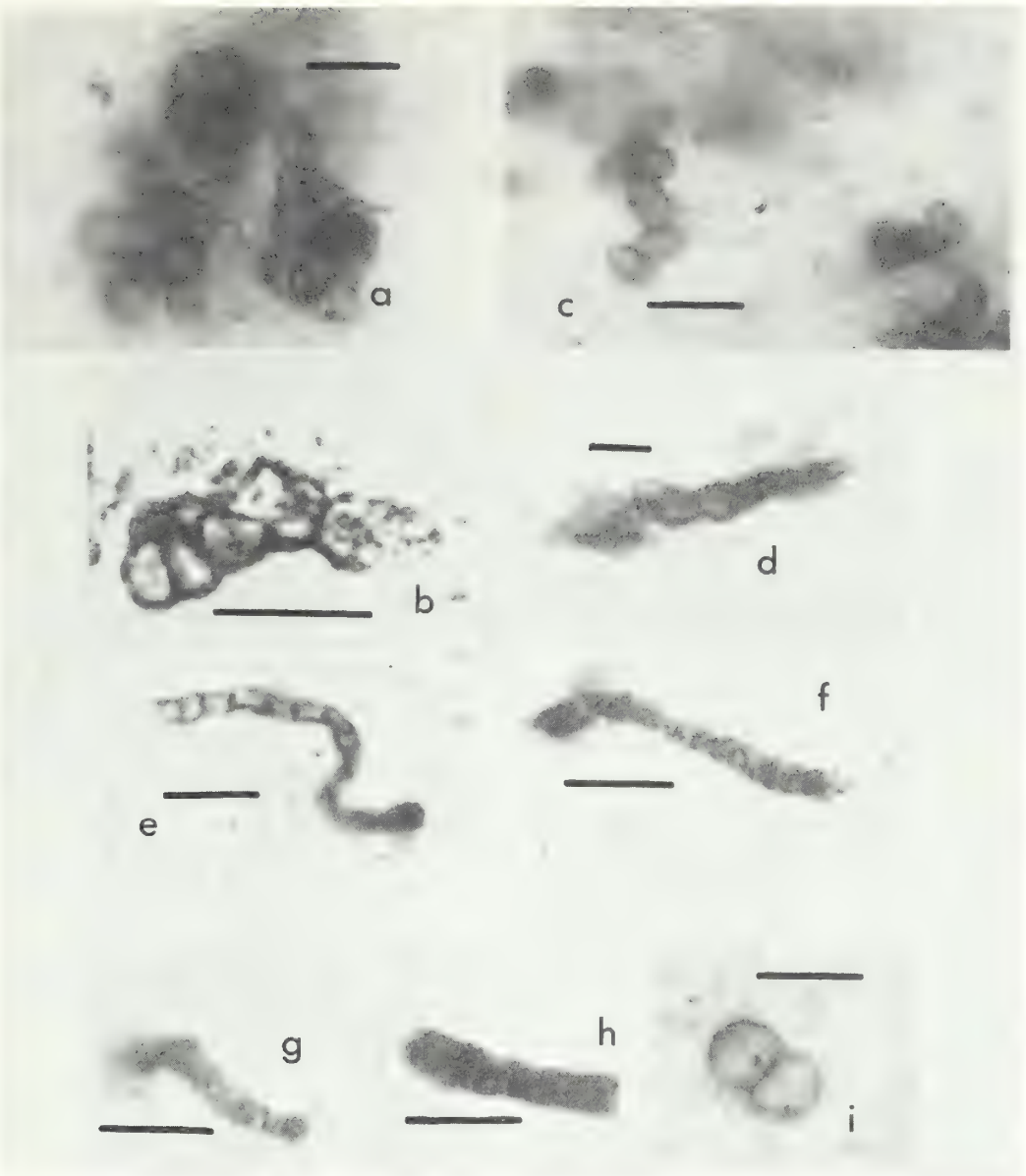

FIGURE 5. Photomicrographs of coccoidal and filamentous microfossils in thin slices of black chert from Divide Mountain.

Microfossils from the Altyn Formation were first discovered in a sample from the Appekunny Creek section (White 1974a,1974b). These are fossils of uncertain taxonomic position occurring as a loosely coiled thallus of branched coenocytic tubular filaments. They occur in a detrital chert grain and show that the microfossils were present at the time of deposition of the sediment and were not introduced at some later stage. Subsequently microfossils were discovered in black cherts found on Divide Mountain (White and Pedone 1975). The microfossils were preserved by silica permineralization in much the same way as many other Precambrian assemblages (Schopf 1975).

Filamentous and coccoidal microfossils resembling modern blue-green algae are the predominant fossils found in the Altyn Formation cherts. The coccoidal forms are generally spherical except where modified by mutual compression of adjacent cells in colonial forms. They range in size from 2 to 12 microns with the majority in the range of 4 to 8 microns in diameter. They occur commonly as three-dimensional clusters of 20 or more cells (Fig. 5a) but also in irregular rows of compressed cells (Fig. 5b), as loosely grouped but separate unicells (Fig. 5c) and sometimes in a pseudofilamentous fashion (Fig. 5d). Most of the coccoidal microfossils are devoid of any internal structures and they are comparable to forms belonging to the modern family Chroococcaceae.

The filamentous forms are unbranched and non-heterocystous and range in diameter from 1 to 5 microns and in length up to 120 microns although

most are less than 30 microns. Many filaments have no internal structures preserved and they probably are discarded sheaths. Filaments with preserved cellular structures do occur and some of these are illustrated in Figs. 5e to 5H. The absence of branching and the lack of heterocysts make the Altyn Formation filamentous microfossils comparable to members of the modern Oscillatoriaceae.

Some of the coccoidal microfossils contain a single peripheral eye spot (Fig. 5i). These occur singly, in pairs or in loosely associated groups of a few cells. They are similar to members of the fossil genus *Glenobotrydion* described from the Bitter Springs Formation of Australia (Schopf 1968; Schopf and Blacic 1971). The dark spots are believed to be organelles and the fossils eukaryotic in nature (Schopf 1968). This interpretation is challenged by Knoll and Barghoorn (1975) as a result of their work on experimental fossilization of modern blue-green algae which shows that such dark spots can be produced by the degradation of protoplasm. The eukaryotic nature of *Glenobotrydion* was supported by Schopf and Oehler (1976) on a basis of cell size distribution and electron transmission studies of the dark spots which appear to them to have an organized structure which would not be apparent in a random aggregation of degraded protoplasm. The positive identification of early eukaryotes is difficult and no certain eukaryotic microfossils have been found so far in the Altyn Formation cherts.

SUMMARY

The Altyn Formation was deposited during the middle Proterozoic some 1500 m.y. ago in shallow water peritidal environments along the northeastern shoreward edge of the Belt basin. A warm dry tropical climate caused the development of evaporitic tidal flats where dolomitization of the carbonate minerals was favored. The vertical sequence within the Altyn Formation indicates a regression with the prograding terrigenous sediments eventually putting an end to carbonate sedimentation. Quartz and microcline grains and lithoclasts of granite and gneiss occur in the Altyn Formation dolarenites indicating a source area in crystalline basement of continental type. Abundant algal mats and stromatolites testify to a thriving community of blue-green algae in the tidal flat environments. In rare instances microorganisms were preserved by silica permineralization and these microfossils show that both coccoidal and filamentous blue-green algae were present. No certain evidence for eukaryotic organisms or metazoans has been found so far in the Altyn Formation.

LITERATURE CITED

ARMSTRONE, R.L. 1975. Precambrian (1500 m.y. old) rocks of central Idaho-The Salmon River arch and its role in Cordilleran sedimentation and tectonics. Am. J. Sci. 275A:437-467.

BATHURST, R.G.C. 1971. Carbonate sediments and their diagenesis. Elsevier, Amsterdam, 620 p.

BLACK, R.F. 1963. Paleomagnetism of part of the Purcell System in southwestern Alberta and southeastern British Columbia. Can. Geol. Surv. Bull. 84. 31 p.

BURCHFIELD, B.C. and G.A. DAVIS. 1975. Nature and controls of Cordilleran orogenesis, western United States: Extensions of an earlier hypothesis. Am. J. Sci. 275A:363-396.

BURWASH, R.A., H. BAADSGAARD, and Z.E. PETERMAN. 1962. Precambrian K-Ar dates from the western Canada sedimentary basin. J. Geophys. Res. 67:1617-;625.

BYERS, C.W. 1976. Bioturbation and the origin of the metazoans: Evidence from the Belt Supergroup, Montana. Geology. 4:565-567.

COLLINSON, D.W. and S.K. RUNCORN. 1960. Polar wandering and continental drift: Evidence of paleomagnetic observations in the United States. Geol. Soc. Am. Bull. 71:915-958.

DAVIES, F.B. and B.F. WINDLEY. 1976. Significance of major Proterozoic high grade linear belts in continental evolution. Nature. 263:383-385.

ECKELMANN, W.R. and J.L. KULP. 1957. Uranium-lead methods of age determination, Part II: North American localities. Geol. Soc. Am. Bull. 68:1117-1140.

EVANS, M.E., BINGHAM, D.K., and E.W. MCMURRY. 1975. New paleomagnetic results from the Upper Belt-Purcell Supergroup of Alberta. Can. J. Earth Sci. 12:52-61.

FOLK, R.L. and J.S. PITTMAN. 1971. Length-slow chalcedony: A new testament for vanished evaporites. J. Sediment. Petrol. 41:1045-1058.

GABRIELSE, H. 1972. Younger Precambrian of the Canadian Cordillera. Am. J. Sci. 272:521-536.

GILETTI, B.J. 1966. Isotopic ages from southwestern Montana. J. Geophys. Res. 71:4029-4036.

GOLDICH, S.S., H. BAADSGAARD, G. EDWARDS, and C.E. WEAVER. 1959. Investigations in radioactivity-dating of sediments. Am. Assoc. Pet. Geol. Bull. 43:654-662.

GULBRANDSEN, R.A., S.S. GOLDICH, and H.H. THOMAS. 1963. Glauconite from the Precambrian Belt Series. Science. 140:390-391.

HAILE, N.S. 1975. Calculation of paleolatitudes from paleomagnetic poles. Geology. 3:174.

HARRISON, J.E. 1972. Precambrian Belt Basin of northwestern United States: Its geometry, sedimentation, and copper occurrences. Geol. Soc. Am. Bull. 83:1215-1240.

HARRISON, J.E. 1973. Epilogue. Belt Symposium, Univ. of Idaho and Idaho Bureau of Mines. 2:1-14.

HARRISON, J.E., A.B. GRIGGS, and J.D. WELLS. 1974. Tectonic features of the Precambrian Belt Basin and their influence on post-Belt structures. U.S. Geol. Surv. Prof. Paper. 866. 15 p.

HARRISON, J.E. and M.W. REYNOLDS. 1976. Western U.S. continental margin: A stable platform dominated by vertical tectonics in the Late Precambrian. Geol. Soc. Am. Abstracts with programs. 8:905.

HOFMANN, H.J. 1969. Attributes of stromatolites. Can. Geol. Surv. Paper, 69-39. 58 p.

HOFMANN, H.J. 1973. Stromatolites: Characteristics and utility. Earth Sci. Rev. 9:339-373.

HOFMANN, H.J. 1975. Australian stromatolites. Geol. Mag. 112:97-100.

HUNT, G.H. 1962. Time of Purcell eruption in southeastern British Columbia and southwestern Alberta. J. Alberta Soc. Petrol. Geol., 10: 438-442.

IRVING, E and J.C. MCGLYNN. 1976. Proterozoic magnetostratigraphy and the tectonic evolution of Laurentia. Phil. Trans. R. Soc. Lond. A. 280:433-468.

KNOLL, A.H. and E.S. BARGHOORN. 1975. Precambrian eukaryotic organisms: A reassessment of the evidence. Science. 190:52-54.

LUCIA, F.J. 1972. Recognition of evaporite-carbonate shoreline sedimentation. In: Rigby, J.K. and Hamblin, W.K. (Editors), Recognition of ancient sedimentary environments. Society of Economic Paleontologists and Mineralogists, Spec. Publ. 16:160-191.

MONGER, J.W.H., J.G. SOUTHER, and H. GABRIELSE. 1972. Evolution of the Canadian Cordillera: A plate-tectonic model. Am. J. Sci. 272:577-602.

OBRADOVICH, J.D. and Z.E. PETERMAN. 1968. Geochronology of the Belt Series, Montana. Can. J. Earth Sci. 5:737-747.

OBRADOVICH, J.D. and Z.E. PETERMAN. 1973. A review of the geochronology of Belt and Purcell rocks. Belt Symposium, Univ. of Idaho and Bureau of Mines. 1:8-9.

PIPER, J.D.A. 1976. Paleomagnetic evidence for a Proterozoic supercontinent. Phil. Trans. R. Soc. Lond. A. 280:469-490.
PRICE, R.A. 1964. The Precambrian Purcell System in the Rocky Mountains of southern Alberta and British Columbia. Bull. Can. Petrol. Geol. 12:399-426.
REID, R.F., D.A. MORRISON, and W.R. GREENWOOD. 1973. The Clearwater orogenic zone: A relict of Proterozoic orogeny in central and northern Idaho. Belt Symposium, Univ. of Idaho and Idaho Bureau of Mines. 1:10-56.
ROSS, C.P. 1959. Geology of Glacier National Park and the Flathead region northwestern Montana. U.S. Geol. Surv. Prof. Paper. 296. 125 pp.
RYAN, B.D. and J. BLENKINSOP. 1971. Geology and geochronology of the Hellroaring Creek stock, British Columbia. Can. J. Earth Sci. 8:85-95.
SCHNEIDER, J.F. 1975. Recent tidal deposits, Abu Dhabi, UAE, Arabian Gulf. In: Ginsburg, R.N. (Editor), Tidal deposits. Springer-Verlag, New York. 209-214.
SCHOPF, J.W. 1968. Microflora of the Bitter Springs Formation, late Precambrian, Central Australia. J. Paleontol. 42:651-688.
SCHOPF, J.W. 1975. Precambrian paleobiology: Problems and perspectives. Ann. Rev. Earth Planetary Sci. 3:213-249.
SCHOPF, J.W. and J.M. BLACIC. 1971. New microorganisms from the Bitter Springs Formation (Late Precambrian) of the north-central Amadeus basin, Australia. J. Paleontol. 45:925-960.
SCHOPF, J.W. and D.Z. OEHLER. 1976. How old are the eukaryotes? Science. 193:47-49.
STEWART, J.H. 1972. Initial deposits in the Cordilleran geosyncline: Evidence of a Late Precambrian (< 850 m.y.) continental separation. Geol. Soc. Am. Bull. 83:1345-1360.
STEWART, J.H. 1976. Late Precambrian evolution of North America: Plate tectonics implication. Geology. 4:11-15.
WALTER, M.R. 1972. Stromatolites and the biostratigraphy of the Australian Precambrian and Cambrian. Spec. Pap. Paleontology. 11. Paleontological Association. London. 256 p.
WHITE, B. 1970. Algal stromatolites, depositional environments and age of the Altyn Formation of Montana. Geol. Soc. Am. Abstracts with programs. 2:719-720.
WHITE, B. 1974a. Microfossils from the Late Precambrian Altyn Formation of Glacier National Park, Montana. Geol. Soc. Am. Abstracts with programs. 5:85.
WHITE, B. 1974b. Microfossils from the Late Precambrian Altyn Formation of Montana. Nature. 247:452-453.
WHITE, B. and V.A. PEDONE. 1975. A new microfossil locality in the Precambrian Altyn Formation of Montana. AAPG-SEPM Annual meeting Abstracts 2:80-81.
WILLIS, B. 1902. Stratigraphy and structure, Lewis and Livingston ranges, Montana. Geol. Soc. Am. Bull. 13:305-352.
ZARTMAN, R.E. and J.S. STACEY. 1971. Lead isotopes and mineralization ages in Belt Supergroup rocks, northwestern Montana and northern Idaho. Econ. Geol. 66:849-860.

PALEOECOLOGY OF THE PALEOCENE BLACK PEAKS FORMATION, BIG BEND NATIONAL PARK, TEXAS[1]

Judith A. Schiebout[2]

INTRODUCTION

The Black Peaks Formation, which contains 29 species of mammals belonging to 28 genera, has yielded the southernmost large fauna of Paleocene mammals from North America. Three exposures of the formation are known, and all three lie within Big Bend National Park (Figure 1). The formation has three principal faunal levels, one 23 meters, one 43-85 meters, and one 137 meters above the base of the formation (Table 1). The lowest level is latest Torrejonian or earliest Tiffanian in age, the second is early Tiffanian, and the third is Clarkforkian.

The first early Tertiary fossils found in Big Bend National Park were discovered by a student on a field trip in 1952 led by Dr. John A. Wilson of the University of Texas at Austin. The Paleocene and Eocene continental deposits in the park had previously been mapped as Cretaceous. The Black Peaks Formation, the underlying Javelina Formation, and the overlying Hannold Hill Formation were named in 1967 in *Geology of Big Bend National Park* by Maxwell, Londsdale, Hazzard and Wilson. This book combines work by Lonsdale on igneous intrusives, by Hazzard on stratigraphy and by Wilson on fossil mammals with Maxwell's extensive description of the region's stratigraphy and structure. My work on the sediments and fauna of the Black Peaks Formation began in 1968 and included both my masters and doctoral research under the direction of John A. Wilson. Detailed descriptions of the sediments and fauna can be found in Schiebout (1974).

PALEOECOLOGY

The 170-meter thick formation is a fluvial deposit laid down by meandering rivers. Montmorillonitic mudstone makes up approximately 60 percent of the formation by volume. The rest is sandstone except for small conglomerate scour fills that comprise less than 2 percent of the formation. Most of the sandstone occurs in bodies 3 to 12 meters thick which show a sequence of bedding and grain size changes indicative of deposition in channels and on point bars of meandering rivers (Figures 2, 3). Trough cross beds predominate in the lower portions of the sandstone bodies which contain the channel lag laid down when streams in flood scoured deeply. Grain size commonly becomes finer upwards. Thin discontinuous sandstone layers in the mudstones formed as crevasse splays, when breaks in the levee allowed bed load to splay out into the flood basin.

The mudstones are overbank deposits. Mudstone layers in shades of red, black, gray, yellow, and gray-green are usually 0.3 to 1.5 meters thick. The layering was produced by variations in the soil-forming processes acting on the sediments. Sedimentary structures were destroyed and individually deposited layers mixed by the activities of plants and animals and by slippage in the mudstone. The color layering makes possible inferences about the Paleocene climate and its variations.

The black and gray layers, which are colored by small amounts of finely disseminated organic matter, formed under reducing conditions when the ground was kept moist and vegetation was abundant (Figure 2). Black mudstones contain more clay-size material than the red ones. Some of the Paleocene flood basin, at times, may have resembled parts of the Amazon Basin described by Sioli (1951:279), where the forests are usually flooded with organic-rich water. When floods met standing water, they quickly dropped their bed load allowing only the finest material to be carried out into the flood basin.

Red mudstone layers formed during periods when flooding was occasional and alluvium dried out and was oxidized between floods. Microcrystalline calcite nodules are common in the red layers and absent from the black layers (Figure 4). Such nodules form in soils in regimes where rainfall is less than 60 centimeters per year (Steel 1974). Some of the silicified wood which is common in the formation shows seasonal rings and some does not. The wood which lacks seasonal rings probably grew during the periods of accumulation of black mudstone or grew near the rivers. The rivers were not intermittent. The wood with seasonal rings reflects the variability in water availability away from the rivers during dry periods. During formation of the red mudstone layers, forest may have given way to savannah in parts of the flood basin. Work in progress by Dr. M. L. Abbott (1976 pers. comm.) on petrified wood from the Black Peaks Formation will yield further information on tree distribution.

The Paleocene climate was both milder and wetter than the present climate of the Big Bend region. The extremes of temperature and scarcity of rainfall which characterize the Big Bend region today were moderated in the Paleocene by greater nearness of the sea. The Black Peaks Formation exposures now lie hemmed in by mountains. In the Paleocene, the Big Bend area lay on an alluvial plain, with the sea much closer than it is today (Figure 1). Moisture-laden Gulf winds could reach the area without impediment. Crocodiles and turtles remained abundant throughout the deposition of the formation, so Paleocene winters must have been mild without prolonged freezes. These climatic changes are mirrored in the differences between the modern sparse desert vegetation growing on the material of the Black Peaks Formation and the fossilized Paleocene trees, the largest of which is at least 2.4 meters in diameter. Of the fifty logs whole enough for diameter to be estimated, the average diameter is approximately a meter.

[1]I am grateful to the U. S. National Park Service for the opportunity to work within Big Bend National Park. I would like to extend special thanks to Dr. John A. Wilson who supervised my research on the Black Peaks Formation when I was a student at the University of Texas at Austin. Conversations on sexual dimorphism in pantodonts with Mr. David C. Parris and on *Hyracotherium* from Baja California with Dr. William J. Morris have been very helpful. Part of this research was supported by grants from the Geology Foundation of the University of Texas at Austin and by a grant from the Geological Society of America.

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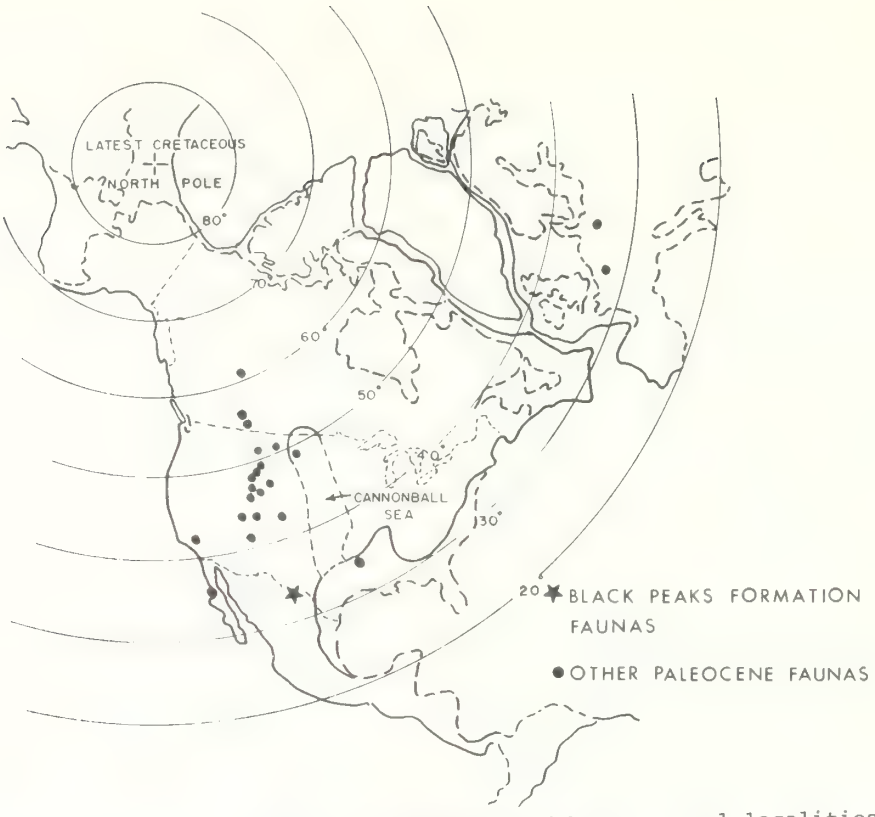

FIGURE 1. Palinspastic map of the geographic distribution of known mammal localities during the Paleocene, modified from Sloan (1969, Fig. 4).

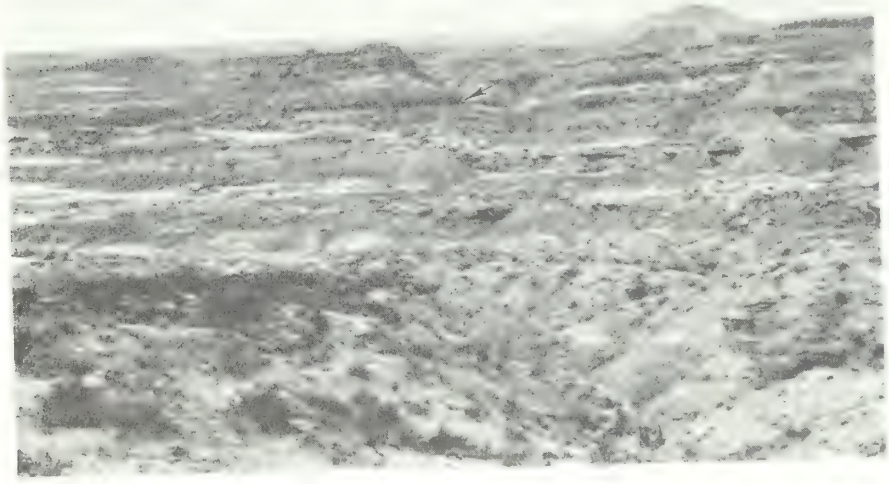

FIGURE 2. View looking southeast across badlands on western Tornillo Flat in which the best exposures of the Black Peaks Formation occur. Arrow indicates a prominent black mudstone layer. Chisos Mountains visible in background

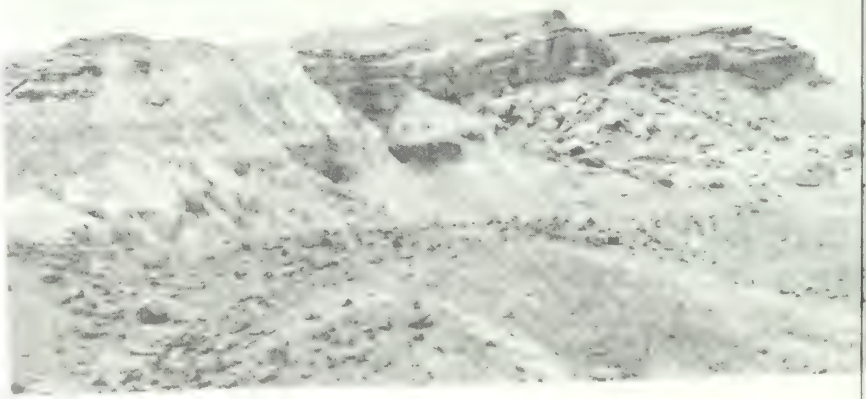

FIGURE 3. View looking northwest at point bar deposits associated with a 1-foot-thick channel sandstone, exposed on western Tornillo Flat.

TABLE 1. Distribution of mammals within the Black Peaks Formation.

Species	Level in Formation(m)						
	23	43[a]	43	49-59	79-85	105	137
Ptilodus mediaevus	x	x	-	-	x	-	-
Ectypodus musculus	-	x	-	-	x	-	-
Parectypodus sloani n. sp.	-	x	-	-	x	-	-
Mimetodon silberlingi	-	x	-	-	x	-	-
Neoplagiaulax douglassi	-	x	-	-	-	-	-
Mesodma sp.	-	x	-	-	-	-	-
?Palaeictops	-	-	-	-	x	-	-
Jepsenella undescribed sp.	-	-	-	-	x	-	-
?Zanycteris	-	-	-	-	x	-	-
Plesiadapis gidleyi	-	-	-	x	x	-	-
Chiromyoides caesor	-	-	-	-	x	-	-
Phenacolemur frugivorus	-	-	-	-	x	-	-
Navajovius kohlhaasae	-	x	-	x	x	-	-
Psittacotherium or Lampadophorus	-	x	-	x	x	x	-
Tricentes truncatus	-	-	-	x	x	-	-
Arctocyon cf. A. ferox	-	-	-	-	x	-	-
undescribed genus and sp. of arctocyonid	-	-	-	x	x	x	-
Promioclaenus acolytus	x	-	-	-	-	-	-
Haplaletes disceptatrix	-	-	-	-	x	-	-
Protoselene opisthacus	-	-	-	x	-	-	-
Phenacodus grangeri	x	-	-	x	x	-	-
Phenacodus cf. P. matthewi	x	x	-	x	x	-	-
Ectocion cf. E. montanensis	-	-	-	x	x	-	-
Periptychus superstes	x	x	-	x	-	-	-
Caenolambda sp.	x	-	-	-	-	-	-
Barylambda jackwilsoni n.	-	-	-	x	-	-	-
Barylambda sp.	-	-	-	-	-	-	x
Titanoides zeuxis	-	-	x	x	-	-	-
Hyracotherium angustidens	-	-	-	-	-	-	x

[a]On eastern Tornillo Flat. All other localities are on western Tornillo Flat.

FIGURE 4. Microcrystalline calcium carbonate nodule, approximately 0.7 m long, in place in gray mudstone.

Vertebrate fossils are not found in place often enough for particular animals to be associated with particular habitats. Teeth of small animals were recovered from lenses of carbonate nodule conglomerate in the floodplain mudstone. These lenses formed as flood waters winnowed out nodules and teeth from floodplain soils and concentrated them in small hollows. Carcasses of most large animals, the size of sheep or larger, appear to have undergone a period of exposure on the floodplain surface before burial. Bones often show evidence of having undergone weathering before burial. Porous bones buried in mudstone served as channels for mineral-laden ground water. Crusts of barite and calcite preserve split and flaked bone surfaces. A partial skeleton of *Caenolambda* (Order Pantodonta) which was quarried out of mudstone must have been exposed quite a while (Figure 5). It occurred in a layer 10-15 centimeters thick. Both mandibles were present, but all teeth had fallen out. Most of the teeth were found scattered among the other bones, and some bones had been broken before burial. Ribs, vertebrae, the occipital condyle, and parts of both scapulae were present. Only one foot showed some articulation. The various elements preserved would be transported at different rates in a fluvial environment (Voorhies 1969), so this specimen must be in place, not a lag deposit.

Many of the Black Peaks species are known only from teeth, so that little new understanding of the functional morphology of Paleocene animals can be gained from them. The best preserved fossil vertebrates from the Black Peaks Formation belong to the Pantodonta, an order of large extinct herbivores. The specimen which I refer to *Titanoides zeuxis* has small canines. Enlarged canines have been considered a *Titanoides* characteristic (Simons 1960). The one previously known specimen of *T. zeuxis* canine is larger than that of the Black Peaks specimen and differs in form, having a posterior blade. I believe that the small canine with a more rounded cross section (Figure 6) indicates that the specimen is a female, in fact, the first identifiable female of the genus *Titanoides* yet discovered. One small isolated fragment of the distinctive male *Titanoides* canine is available from the Black Peaks Formation. The larger canines of the male may have been used in intraspecific combat over females or, if *Titanoides* was a herd animal, in defense of the herd. Pantodonts are still too poorly known for any conclusions to be drawn regarding their population structure.

Important paleogeographic information can be drawn from the Black Peaks faunas. Sloan (1969) listed differences between the southern and northern Paleocene faunas of North America known at that time (Table 2). The Black Peaks fauna agrees with Sloan's generalizations for a southern fauna in having a high proportion and diversity of phenacodontid condylarths, including *Periptychus* and *Protoselene*, and in having only two plesiadapoid primates, in contrast to the six species of the early Tertiary Bison Basin localities in Wyoming (Gazin 1956). Differences in diversity reflect the taxonomic practices of different authors and may not indicate a true geographic difference. Species unique to the Black Peaks Formation include the pantodont *Barylambda jackwilsoni*, the multituberculate *Parectypodus sloani*, and an undescribed species of the insectivore *Jepsenella* (Schiebout 1974). *Titanoides zeuxis* is the most abundant pantodont and one of the most abundant fossil animals from the Black Peaks Formation. *Titanoides* can no longer be considered solely a northern animal. *Ectypodus musculus*, found only in the Tiffany fauna of Colorado and the Black Peaks Formation, may be restricted to the south. A single specimen of *Hyracotherium angustidens* occurs at the uppermost fossiliferous level of the Black Peaks Formation in association with the remains of a barylambdid pantodont. This occurrence is only the third occurrence of *Hyracotherium* reported from rocks older than the Eocene. One of the other occurrences is in Baja California (Morris 1968) and one in Wyoming (Jepsen and Woodburne 1969). The Baja specimens may be less derived than any other known *Hyracotherium*. The ancient horse ancestor

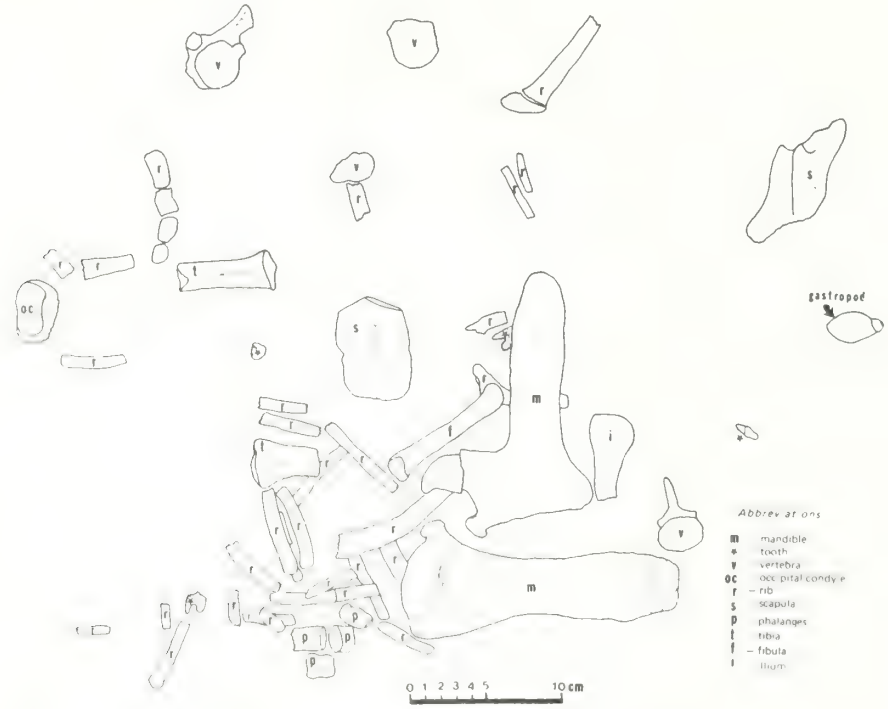

FIGURE 5. Orientation diagram of Texas Memorial Museum specimen 41377-1, *Caenolambda* sp., as preserved in gray mudstone.

FIGURE 6. *Titanoides zeuxis*, Texas Memorial Musuem 41217-1, fragmentary left half of skull with upper C-M^3, lateral, ventral.

Hyracotherium may eventually prove to have developed in the southern faunas, although material is far too scarce for a definite statement.

Differences from the European localities described by Russell (1964) are even more marked than the differences from northern localities, despite latitudinal similarities in the Paleocene and mounting evidence that a land passage eastward from North America to Europe may have been climatically much more passable than the route westward over the Bering Sea (McKenna 1973; Dawson et al. 1976). Only four of the genera reported from Cernay, France and 1 of the 13 genera from the Walbeck locality in Germany also occur in the Black Peaks Formation. These differences may result in part from differences in age.

CONCLUSIONS

Exposures of the Black Peaks Formation in Big Bend National Park are sufficient for detailed analysis of depositional environments leading to the conclusion that the formation was laid down by meandering rivers flowing across an alluvial plain to the Gulf of Mexico. Abundant crocodiles and turtles, which cannot stand prolonged freezes, indicate mild temperatures. Variations of greater than seasonal extent in rainfall affected soil-forming processes to produce prominent color layering in the overbank mudstones, which make up 60% of the formation. The fauna, which is the southernmost large fauna of Paleocene mammals, shows strong similarities to other North American Paleocene localities but is strongly dissimilar to French Paleocene localities in the same paleolatitude.

The scarcity of material of individual taxa and poor preservation make extensive new functional morphological conclusions impossible. Future work may be expected to increase both the samples of individual taxa and the number of taxa, with a concomitant increase in data from the Black Peaks fauna on functional morphology and biogeography of the Paleocene.

LITERATURE CITED

DAWSON, J. R., R. M. WEST, WANN LANGSTON, JR., and J. H. HUTCHISON. 1976. Paleocene terrestrial vertebrates: northernmost occurrence, Ellesmere Island, Canada. Science. 192: 781-782.

GAZIN, C. L. 1956. Paleocene mammalian faunas of the Bison Basin in south-central Wyoming. Smithson. Misc. Coll. 131:1-57.

JEPSEN, G. L. and M. O. WOODBURNE. 1969. Paleocene hyracothere from Polecat Bench Formation, Wyoming. Science. 164:543-547.

MAXWELL, R. A., J. T. LONSDALE, R. T. HAZZARD, and J. A. WILSON. 1967. Geology of the Big Bend National Park, Brewster County, Texas. U. T. Bur. Econ. Geol., Publ. 6711:1-320.

MCKENNA, M. C. 1973. Sweepstakes, filters, corridors, Noah's arks, and beached Viking funeral ships in palaeogeography. *In:* Implications of continental drift to the earth sciences, ed. D. H. Tarling and S. K. Runcorn. 1:295-308.

TABLE 2. Geographic distribution in western North America of selected animals and groups during the Torrejonian-Clarkforkian.[a]

	no. sp. plesiadapoid primates	no. sp. Hyopsodontinae	no. sp. Mioclaeninae	no. sp. phenacodontids	no. sp. Protoselene	no. sp. Periptychus	no. sp. Titanoides
NORTHERN							
Clark Fork, Wyoming	2	1	-	5	-	-	-
Buckman Hollow, Wyoming	3	-	-	4	-	-	-
Bear Creek, Montana	-	1	-	1	-	-	-
Olive, Montana	1	1	-	-	-	-	1
Silver Coulee, Wyoming	1	-	-	2	-	-	3
Dell Creek, Wyoming	3	-	-	-	-	-	-
Circle, Montana	1	1	-	1	-	-	-
Twin Creeks, Wyoming	1	2	-	2	-	-	-
Scarritt Quarry, Montana	2	2	1	6	-	-	2
Bison Basin, Wyoming	6	4	2	4	1	-	1
Shotgun, Wyoming	1	1	1	-	-	1	-
Battle Mountain, Wyoming	2	1	1	3	-	-	-
Gidley Quarry, Montana	1	2	2	2	-	-	1
Rock Bench, Wyoming	-	-	-	1	-	-	-
SOUTHERN							
Plateau Valley, Colorado	-	-	-	4	-	-	2
Black Peaks, Texas (43-85m)	2	2	1	3	1	1	1
Tiffany, Colorado	1	-	-	4	-	1	-
Torrejon, New Mexico	-	1	9	2	1	2	-
Laudate, California	-	-	1	1	-	-	-
Dragon, Utah	-	1	5	-	-	1	-

[a]Information on faunas other than the Black Peaks fauna was taken from Russell 1967.

MORRIS, W. J. 1968. A new early Tertiary perissodactyl, *Hyracotherium seekinsi*, from Baja California. Los Angeles Co. Mus. Contrib. Sci., no. 151:1-11.

RUSSELL, D. E. 1964. Les Mammiferes Paleocenes d'Europe. Mem. Mus. Nation. Hist. Nat., Ser. C, 13:1-324.

[illegible]. 1967. La Paleocene Continental d'Amerique Du Nord. Mem. Mus. Nation. Hist. Nat., Ser. C, 16:1-99.

SCHIEBOUT, J. A. 1974. Vertebrate paleontology and paleoecology of Paleocene Black Peaks Formation, Big Bend National Park, Texas. Tex. Mem. Mus. Bull. 24:1-88.

SIMONS, E. L. 1960. The Paleocene Pantodonta. Amer. Philos. Soc. Trans. 50:1-99.

SIOLI, HAROLD. 1951. Zum Alterungsprozess vo Flüssen and Flusstypen im Amazonasgebiet. Archiv für Hydrobiologie, Bd. 45, Heft 3:267-283.

SLOAN, R. E. 1969. Cretaceous and Paleocene terrestrial communities of western North America. Proc. N. Amer. Paleo. Convention. Part E:427-453.

STEEL, R. J. 1974. Cornstone (fossil caliche Its origin, stratigraphic and sedimentologi cal importance in the New Red Sandstone, western Scotland. Jour. Geology. 82:351-36

VOORHIES, M. R. 1969. Taphonomy and populati dynamics of an early Pliocene vertebrate fauna, Knox County, Nebraska. Wyo. Univ. Contrib. Geol. Spec. Paper 1:1-69.

PALEOECOLOGY OF PETRIFIED WOODS FROM THE AMETHYST MOUNTAIN "FOSSIL FOREST," YELLOWSTONE NATIONAL PARK, WYOMING[1]

William J. Fritz and Lanny H. Fisk[2]

INTRODUCTION

One of the most interesting but least studied features of Yellowstone National Park is its unique petrified "forests" consisting of many layers of both upright petrified stumps and horizontal logs. These "forests" are exposed in several areas in the northern part of the park. They have been most extensively studied at the "Fossil Forest" locality on Amethyst Mountain in the northeastern part of the park (Figure 1). The "forests" in this area are Middle Eocene in age and belong to the Lamar River Formation which is part of the Absaroka Volcanic Supergroup (Smedes and Prostka 1972). The classical interpretation of these remains is that successive living forests were buried by volcanic ejecta and mud flows (Holmes 1878, 1879; Knowlton 1899; Dorf 1960, 1964, 1974).

Since the initial interpretations, surprisingly little detailed work has been done on the "Fossil Forest." Descriptive work on the fossil leaves, needles, pollen, and spores has revealed the preservation of a strange admixture of plant life representing cool temperate to tropical climates (Knowlton 1899; Dorf 1960; Fisk and DeBord 1974a, 1974b; Fisk 1976a). Such heterogeneity is common in transported Paleogene floras but is surprising for forests interpreted as having been buried *in situ*. One possible explanation is that the actual forests were tropical to sub-tropical and the anomalous cool temperate floral elements such as the leaves and pollen were washed in from nearby mountains by intense rain showers and resultant flooding often associated with volcanic eruptions. This interpretation explains the heterogenous mixture of easily transportable plant parts (i.e., leaves, pollen, and spores) but assumes that at least the upright trees of the "forests" are still in the position in which they originally grew. The work we report in this paper was designed to test both this interpretation and the resulting assumption by attempting to identify the actual trees in the "forests."

Several species of petrified wood have been previously described from the Yellowstone deposits (Knowlton 1899; Read 1930; Conard 1930; Beyer 1954; Wheeler and Barghoorn 1976). Wheeler and Barghoorn reported a mixture of both temperate and tropical woods but unfortunately, these and the other previously described woods were not collected from known stratigraphic horizons and came from several different localities. Thus, the wide range of ecological types represented could be accounted for by pre-supposing changing climates during the time periods between volcanic eruptions. The purpose of this study was to describe and identify wood from the stumps and logs from a single "forest" to determine if a similar mixture exists.

FIELD AND LABORATORY PROCEDURES

The site chosen for this study was the Amethyst Mountain "Fossil Forest" (Figure 2) where a detailed measured section had previously been completed by Fisk (1976a). The measured section contained 66 lithologic units, 41 of which contained upright petrified stumps (Figure 3). Unit 30 was chosen from this section since it contained numerous stumps and logs and could be traced laterally for a horizontal distance of about 154 meters (Figures 4 and 5). In addition, numerous pollen samples collected from this unit had yielded well-preserved pollen and spores; abundant well-preserved leaf fossils were also present for future correlation studies. Unit 30 was also one of the least hazardous levels upon which to work.

During the summers of 1974-76 samples of petrified wood were collected from the 64 logs and stumps exposed on Unit 30. In addition, each stump or log within the unit was assigned a number, its orientation was recorded (i.e., whether horizontal, vertical, or diagonal) and its position was accurately located on a field map (Figure 6). Since recent work on orientations of petrified horizontal logs from several areas of the park has shown that the logs tend to be oriented in the same direction (Coffin 1976), the compass orientations of the horizontal logs on Unit 30 were also recorded.

The woods were identified in the field with a 16X hand lens to three major types: Type I wood without resin ducts (principally Taxodiaceae); Type II wood with resin ducts (primarily Pinaceae); and Type III wood with vessels (angiosperms). In the laboratory, ground thin sections were prepared of each wood sample and identification to the lowest possible taxa was made using such standard references as Record and Hess (1943), Greguss (1947, 1955, 1967, 1969), Metcalfe and Chalk (1950); Jane (1956), Kribs (1968), and Panshin and de Zeeuw (1970). Comparisons were also made with other previously described fossil woods (particularly Conard 1930; Read 1930; Beyer 1954; Kruse 1954; Gregory 1968; Prakash 1968; Roy and Stewart 1971; Roy 1972; Roy and Hills 1972) and with thin sections of modern woods. Detailed anatomical descriptions of extant woods were also consulted (e.g., McLaughlin 1933; Pierce 1936; Phillips 1941; Stark 1954; Kukachka 1960). Also helpful were the numerous publications of S. J. Record and R. W. Hess (see Metcalfe and Chalk 1950 for a partial list).

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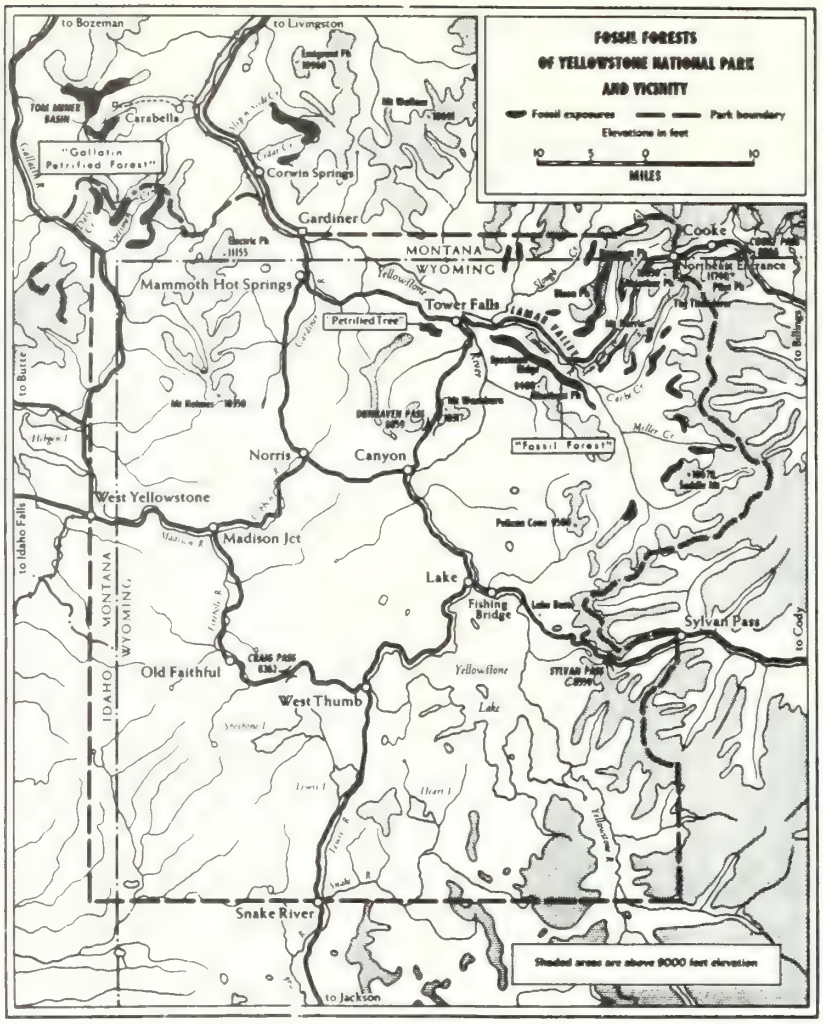


FIGURE 1. Map of Yellowstone National Park showing the various exposures of petrified "forests" in the northern part of the park. (From Fisk 1976b.)

FIGURE 2. Amethyst Mountain "Fossil Forest." Site of the measured section was the exposure in the center of the photo. Unit 30 is approximately two-thirds of the way to the top.

RESULTS AND DISCUSSION

Of the 64 stumps and logs on Unit 30, 53% were in a horizontal position, representing a higher percentage than has been previously suspected. Of the remaining stumps, only 39% were vertical and 8% were diagonal, that is leaning at an angle greater than 15° (Figure 7). Compass orientation measurements of the logs reveals a rather strong alignment in a general northwest-southeast direction (Figure 8). The entombing debris flows may have oriented the logs in this direction. A similar interpretation was made by Coffin (1976). Field identifications were only partially accurate (ca. 80-85%) due to the obscuring of important identifying features by surface weather. Thin sections demonstrated that 83% of the trees were gymnosperms, with Type II woods being the most abundant; angiosperms were represented by only 17% of the trees (Figure 9).

Of the Type I woods, *Sequoia* was the most abundant, agreeing with previous reports on the coniferous woods of Yellowstone (Knowlton 1899; Read 1930; Beyer 1954). Under present day conditions *Sequoia* grows in warm temperate environments. A second Type I wood found was *Juniperus* which has also been reported from the Amethyst Mountain "Fossil Forest" as pollen (Fisk 1976a). Junipers today are usually associated with a cool temperate environment. Another Type I wood found is very different from *Sequoia* or anything in the Taxodiaceae. This wood has anatomical similarities to *Podocarpus* or at least appears to be a member of the Podocarpaceae. If these specimens really

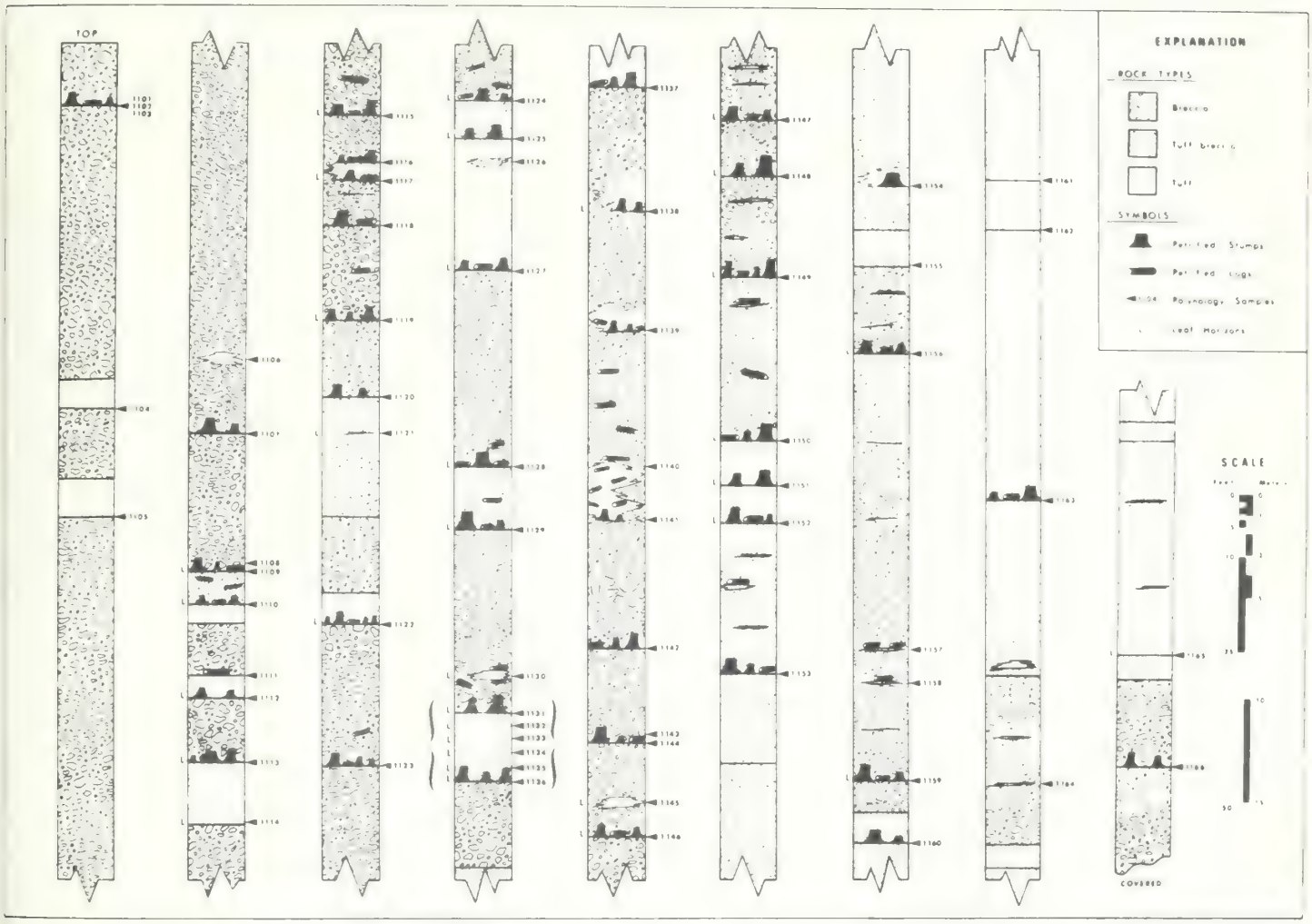


FIGURE 3. Measured section from Amethyst Mountain "Fossil Forest" showing the 66 lithologic units exposed in this area. Unit 30 is indiated by brackets. (From Fisk 1976a.)

FIGURE 4. Amethyst Mountain "Fossil Forest" indicating the location of unit 30.

FIGURE 5. Close-up view of unit 30 showing some of the exposed stumps and logs.

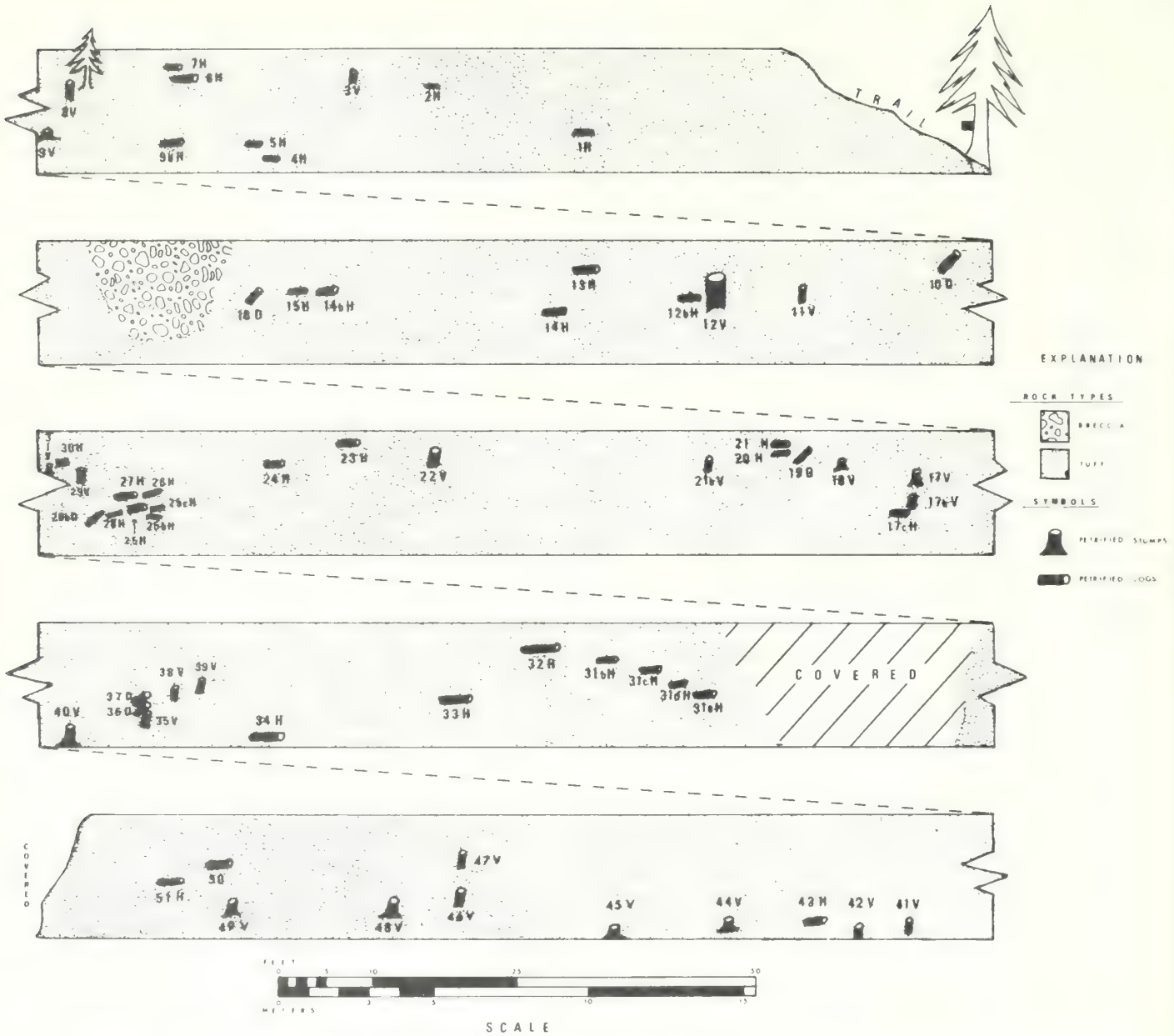
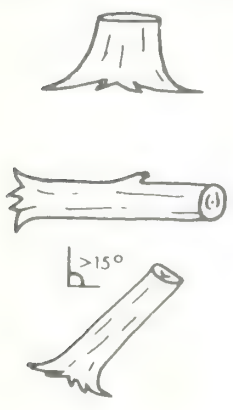


FIGURE 6. Detailed illustration of unit 30 showing the position of each stump and log within the unit.



25 = 39%

34 = 53%

5 = 8%

64 Total

FIGURE 7. Percentage of horizontal, vertical, and diagnonal tress found in unit 30.

FIGURE 8. Orientations of the horizontal logs on unit 30.

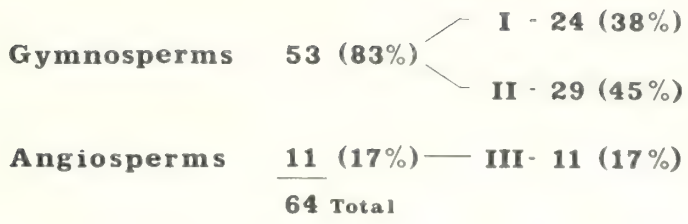


FIGURE 9. Relative abundance of the three types of wood found on unit 30.

TABLE 1. Summary of woods identified from unit 30 of Amethyst Mountain :Fossil Forest" showing orientations, plant parts represented, and modern climatic ranges.

		ORIENTATIONS			PLANT PARTS REPRESENTED			CLIMATE			
	TAXON	Horizontal	Vertical	Diagonal	Wood	Leaves	Pollen	Tropical	Sub-tropical	Warm Temperate	Cool Temperate
CUPRESSACEAE:	*Juniperus* sp.	1			+		+			+	+
PODOCARPACEAE:	*Podocarpus* sp.	1	1	1	+		+	+	+	+	
TAXODIACEAE:	*Sequoia* sp.	7	2	2	+	+	+			+	
	Unidentified	3	4		+						
PINACEAE:	*Picea* (or *Larix*)	4	4	1	+	+	+				+
	Pinus spp.	12	9		+	+	+	+	+	+	+
ARALIACEAE:	Gen. indet.		1		+	+		+	+		
BETULACEAE:	*?Betula* sp.		2		+	+	+		+	+	+
LAURACEAE:	Gen. indet.	1	1		+	+		+	+		
MAGNOLIACEAE:	Gen. indet.	1	1	1	+	+	?	+	+	+	
SALICACEAE:	*?Populus* sp.	1			+	+	+	+	+	+	+
UNIDENTIFIED		2			+						
		34	25	5				6	7	7	5

are *Podocarpus*, it would be the first known fossil wood of this genus from North America, except possibly for the several woods referred to as *Podocarpoxylon* by Torrey (1923). However, *Podocarpus* pollen has been reported from the Amethyst Mountain "Fossil Forest" (Fisk 1976a). The present day range of *Podocarpus* is warm temperate to tropical. The farthest north it currently extends is the mountainous region of northern Mexico.

Of the Type II woods, coniferous woods with resin ducts, *Pinus* is the most abundant. Since pines tend to be very ubiquitous, it is impossible to draw many paleoecological conclusions from a generic assignment alone. The closest living species appear to be hard pines of the California coast (Read 1930). *Picea* (spruce) or possibly *Larix* (larch) is also represented in the Type II woods. It is almost impossible to distinguish with certainty the woods of *Picea* and *Larix* on the basis of wood anatomy (Hudson 1958). However, at least under present day conditions *Picea* and *Larix* are both restricted to cool temperate climates. A third Type II wood has anatomical features of both extant *Pinus* and *Pseudotsuga* and appears to be identical with specimens referred to *Pinus pseudotsugoides* by Beyer (1954).

The Type III or angiospermous woods are represented by several tropical types and by some that are more temperate in habitat. There are several woods from the Magnoliaceae which contain inflated oil cells in the rays, a feature usually found only in the tropical species of this family (McLaughlin 1933; Record and Hess 1943). Also present was the wood of some member of the Araliaceae. This wood has very indistinct growth rings, a condition which is also usually associated with a more equable environment. A member of the Lauraceae was also represented and due to the nature of the growth rings also appears to be tropical. A more

temperate wood with very distinct growth rings--a condition associated with seasonal changes and temperate conditions--is a member of the Salicaceae, possibly *Populus*. A *Betula*-type wood with distinct growth rings was also present. A taxonomic list with paleoclimatological ranges is given in Table 1.

As previously stated, a wide variety of ring types are found in the woods from Unit 30. Rings vary from extremely strong in the conifers and several of the deciduous types to very poor or almost non-existent in the laurel and aralia. This range of ring types would seem to indicate trees growing under several distinct environmental conditions.

SUMMARY AND CONCLUSIONS

From the petrified woods identified in this study, it appears that the strange admixture of ecological indicators seen in the pollen and leaves of Yellowstone National Park's "Fossil Forest" is also found in the wood from the stumps and logs in a single "forest." The mixture is present in both the vertical stumps and horizontal logs (Table 1). We feel that there are at least four and possibly several other ways to explain this mixture. 1) The climate in the sedimentary basin may have been tropical to subtropical as previously suspected and the temperate indicators (including some of the upright stumps) have been transported in, proably with the volcanic mudflows. 2) The climate at the depositional site may have been temperate, and (as unlikely as it may seem) the warm climate indicators have been transported in, presumably to a higher sedimentary basin. 3) All or most of the various climatic indicators may be allochthonous and perhaps none was actually growing at the depositional site. 4) The possibility must also be kept in mind that Eocene plants may not have grown under climatic conditions similar to their living counterparts and thus no paleoclimatic or paleoecologic conclusions are justified.

In any regards, the results of this study suggest that the paleoenvironment of the "Fossil Forest" was much more complex than has been previously suspected. The facts so far available do not allow any of the possible explanations to be ruled out. In fact, considerably more work will be necessary before any one of the four explanations can be considered more reasonable than the others. For those who like economy in hypotheses we would suggest that the idea of allochthonous logs and stumps be further tested. Other planned studies will include work on the petrified logs and stumps on successive layers above and below Unit 30 to see if they contain a similar mixture. Other plant remains, such as leaves, needles, cones, pollen, and spores. from these units should also receive more work to serve as a check on the wood identifications. In the meantime, various investigators working on the Yellowstone fossil "forests" should continue to use multiple working hypotheses in searching for the "correct" paleoecological interpretation.

LITERATURE CITED

BEYER, A. F. 1954. Petrified wood from Yellowstone Park. Amer. Midl. Natur. 51(2):553-567.

COFFIN, H. 1976. Orientation of trees in the Yellowstone Petrified Forests. Jour. of Paleontology 50(3):539-543.

CONARD, H. S. 1930. A *Pityoxylon* from Yellowstone National Park. Amer. Jour. Bot. 17: 547-553.

DORF, E. 1960. Tertiary fossil forests of Yellowstone National Park, Wyoming. pp. 253-260 *In* Billings Geological Society, 11th Annual Field Conference. D. E. Campau and H. W. Anisgard, editors.

_____. 1964. The petrified forests of Yellowstone Park. Sci. Amer. 210(4):106-114.

_____. 1974. Early Tertiary fossil forests of Yellowstone Park. pp. 108-110 *In* Rock Mechanics: The American Northwest, Third International Congress on Rock Mechanics, Expedition Guide, Barry Voight (Editor). Experiment Station, College of Earth and Mineral Sciences, The Pennsylvania State University, University Park, Pennsylvania.

FISK, L. H. 1976a. Palynology of the Amethyst Mountain "Fossil Forest," Yellowstone National Park, Wyoming. Ph.D. Dissertation, Loma Linda University, Loma Linda, California.

_____. 1976b. The Gallatin "Petrified Forest": a review. Mont. Bureau of Mines and Geology Sp. Pub. 73, The Tobacco Root Geological Society 1976 Field Conference Guidebook, pp. 53-72, Mont. College of Mineral Science and Technology, Butte, Mont.

_____ and P. DEBORD. 1974a. Palynology of the "Fossil Forest" of Yellowstone National Park, Wyoming (abst.). Amer. Jour. Bot. 61(5, Suppl.):15-16.

_____. 1974b. Plant microfossils from the Yellowstone fossil forests: preliminary report (abst.). Geological Society of America, Abstracts with Programs. 6(5):441-442.

GREGORY, I. 1968. The fossil woods near Holley in the Sweet Home Petrified Forest, Linn County, Oregon. The Ore Bin 30(6):1-20.

GREGUSS, P. 1947. The identification of Central European dicotyledonous trees and shrubs based on xylotomy. Akademiai, Budapest.

_____. 1955, Identification of living gymnosperms on the basis of xylotomy. Akademiai, Budapest.

_____. 1967. Fossil gymnosperm woods in Hungary. From the Permian to the Pliocene. Akademiai, Budapest.

_____. 1969. Tertiary angiosperm woods in Hungary. Akademiai, Budapest.

HOLMES, W. H. 1878. Report on the geology of the Yellowstone National Park. *In* U. S. Geological Survey, territories of Wyoming and Idaho (1883 edition): twelfth annual report, pt. 2, pp. 1-57.

_____. 1879. Fossil forests of the volcanic Tertiary formations of Yellowstone National Park. U. S. Geol. Surv. Terr. Bull. 2:125-132.

HUDSON, R. H. 1958. The value of the fusiform ray in separating the genera *Picea* and *Larix*. Jour. Inst. Wood Sci. 2:22-30.

JANE, F. W. 1956. The structure of wood. Adam Charles Black, Ltd., London.

KNOWLTON, F. H. 1899. Fossil flora of the Yellowstone National Park. U. S. Geol. Surve., Monograph 32(2):651-791

KRIBS, D. A. 1968. Commercial foreign woods on the American market. Dover, New York.

KRUSE, H. O. 1954. Some Eocene dicotyledonous woods from Eden Valley, Wyoming. Ohio Jour. Sci. 54(4):243-268.

KUKACHKA, F. B. 1960. Identification of coniferous woods. Madison Wisc. Forest Products Research Lab., Tappi 43(11):887-896.

MCLAUGHLIN, R. P. 1933. Systematic anatomy of the woods of the Magnoliales. Tropical Woods. 34:3-39.

METCALFE, C. R. and L. CHALK. 1950. Anatomy of the Dicotyledons. 2 Vols. Oxford Univ. Pres., London.

PANSHIN, A. J. and C. DE ZEEUW. 1970. Textbook of wood technology. 3rd Edition, Vol. I. McGraw-Hill, New York.

PHILLIPS, E. W. 1941. The identification of coniferous woods by their microscopic structure Jour. Linn. Soc. Bot. 52(343):259-320.

PIERCE, A. S. 1936. Anatomical interrelationships of the Taxodiaceae. Tropical Woods 46:1-15.

PRAKASH, U. 1968. Miocene fossil woods from the Columbia basalts of Central Washington, III. Palaeotographica 122(B):183-200.

READ, C. B. 1930. Fossil floras of Yellowstone National Park, Part 1, Coniferous woods of Lamar River flora. Carnegie Inst. Washington Pub. 461:1-19.

RECORD, S. J. and R. W. HESS. 1943. Timbers of the New World. Yale Univ. Press, London.

ROY, S. K. 1972. Fossil wood of Taxaceae from the McMurray formation (Lower Cretaceous) of Alberta, Canada. Can. Jour. Bot. 50(2):349-352.

_____ and L. V. HILLS. 1972. Fossil woods from the Beaufort Formation (Tertiary), northwestern Banks Island, Canada. Can. Jour. Bot. 50(12):2637-2648.

_____ and W. N. STEWART. 1971. Oligocene woods from the Cypress Hills Formation in Saskatchewan, Canada. Can. Jour. Bot. 49(11):1867-1877.

SMEDES, H. W. and H. J. PROSTKA. 1972. Stratigraphic framework of the Absaroka volcanic supergroup in the Yellowstone National Park region. U. S. Geol. Surv., Prof. Paper 729-C:C1-C33.

STARK, E. W. 1954. Wood anatomy of the Betulaceae indigenous to the United States. Agr. Exp. Sta. Purdue Univ. Bull. 606:3-26.

TORREY, R. E. 1923. The comparative anatomy and phylogeny of the Coniferales. Part 3 - Mesozoic and Tertiary coniferous woods. Mem. Bost. Soc. Nat. Hist. 6(2):41-106.

WHEELER, E. and E. S. BARGHOORN. 1976. Fossil dicotyledonous woods of Yellowstone National Park. Bot. Soc. Amer., Program with abstracts p. 33. [Paper presented at the 27th Annual AIBS meetings, New Orleans, LA.]

COASTAL PARAMETERS RELATIVE TO HARBOR DESIGN[1,2]

William F. Rittschof[3], Albert B. Dickas[3] and John J. Fisher[4]

INTRODUCTION

The proper construction of engineering structures within the coastal zone has long been a geological and engineering problem. Population pressure in the coastal zone is steadily increasing, forcing construction of both recreational and protective structures. The National Park Service of the Department of the Interior is developing lakefront property along the Wisconsin shoreline of southwestern Lake Superior for the Apostle Islands National Lakeshore, and as such a harbor facility is required. It is the purpose of this study to supply baseline coastal geological and hydrodynamic data for a federally required Environmental Impact Statement on the proper placement and construction of such a facility.

There has been a historical lack of concern for environmental impact of structures built in the coastal zone, especially in remote areas such as those found along the Lake Superior shoreline. Therefore, techniques used in this study must be taken from the existing literature of similar studies in other more developed areas. Such studies have been conducted by the U.S. Army Corps of Engineers (1974), their Coastal Engineering Research Center (1966), Berg (1968), Bruun (1955, 1963), Bajorunas (1960), Engstrom (1974), Davis and others (1972), Hayes and others (1973) and Loy (unpublished 1962).

Once it has been established that a structure is needed, certain questions must be answered. What forces will work upon the structure? What natural processes will be interrupted or altered by its construction? What is the most suitable site on which to build the structure and how can it be built to minimize the alteration of these natural processes?

In this study, an attempt to answer these questions has been made in two phases. Phase I was initiated September 4, 1974 and was terminated January 31, 1975. This phase covered autumn and early winter conditions on the western half of Little Sand Bay. Phase II was initiated May 28, 1975 and terminated September 15, 1975. This phase was conducted identically to Phase I and covered the late spring and summer conditions existing in the entire Little Sand Bay area. This process allowed for a yearly observation (February to May excluded due to ice cover) of the western half of the bay (that area originally under consideration for dock placement) and a season observation of the eastern half of the bay (that area under consideration as alternate dock site).

LOCATION AND DESCRIPTION OF AREA

The study area is a small, semi-protected reentrant located on Wisconsin's shoreline of Lake Superior known as Little Sand Bay (Fig. 1). It encompasses the offshore waters to an arbitrary depth of 12 m between 90°50' and 90°55' west longitude and 46°55' and 47°00' north latitude on the northwestern side of Point Detour on the Bayfield Peninsula. The onshore area is located within the Lake Superior lowland physiographic province, an area which consists of a cliffed and embayed shoreline, portions of which face the Apostle Islands (Hough 1958).

Little Sand Bay is underlain by ancient Keweenawan (Precambrian) lava flows (not exposed in the study area) and overlying younger sandstone units of late Keweenawan time which comprise the Bayfield group. The specific unit of the Bayfield group which crops out at the western headland of Little Sand Bay is the Chequamegon sandstone, which is made up of predominantly quartzitic grains with an average diameter of 0.50 to 0.25 mm (1.0-2.0ϕ), and are well-sorted and skewed toward the finer sizes (Hamblin 1961).

Fig. 1 shows the general morphology of the Bay as well as the spatial relationship of Sand and York Islands to the bay. This island configuration affords Little Sand Bay some protection as a harbor along this exposed coast. The unnamed cliffed headland to the immediate west of the study area has an elevation of about 198 m and is composed of Chequamegon sandstone which crops out near the waterline. The northeastern, more prominent Point Detour headland has an elevation of approximately 195 m and is composed of unconsolidated glacial till. This headland affords some protection to the bay from northeasterly storms.

Sand Island, located approximately 3.2 km off the mainland, is "attached" to the mainland by a submerged tombolo with a minimum depth of 1.2 m (direct measure with fathometer). This tombolo originates at the mouth of the Sand River and extends northwesterly to intersect Sand Island on its southeast sector (Lake Survey District, Corps of Engineers, Chart L.S. 96). The importance of this tombolo lies in its ability to attenuate wave energy due to its shallow depth. This fact, and the position of Sand Island to the northwest of the north-south axis of Little Sand Bay, affords protection to the bay from the predominant northwesterly approaching storms (National Weather Bureau 1974).

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[2]The authors wish to offer their thanks and acknowledge the aid of the following individuals: Mr. Paul Ruez, formerly on the geologic staff of the University of Wisconsin-Superior, for his valuable field aid; Mr. Pat H. Miller (Superintendent) and Mr. Warren Bielenberg (Naturalist), of the Apostle Islands National Lakeshore staff for their interest and logistical assistance; and Mr. Joel Kussman of the National Park Service, Denver Service Center, for his original and helpful comments and suggestions. This acknowledged aid was administered during the phases of field research and contract report writing supported by National Park Service contracts CX-2000-5-0013 (1974) and CX-2000-5-0034 (1975), of which this paper is a partial summary. More complete details are contained in the 1976 M.S. thesis by William F. Rittschof titled "Coastal Parameters Relative to Harbor Design" (University of Rhode Island), and the two in-house contract reports relating to the above numbered contracts.

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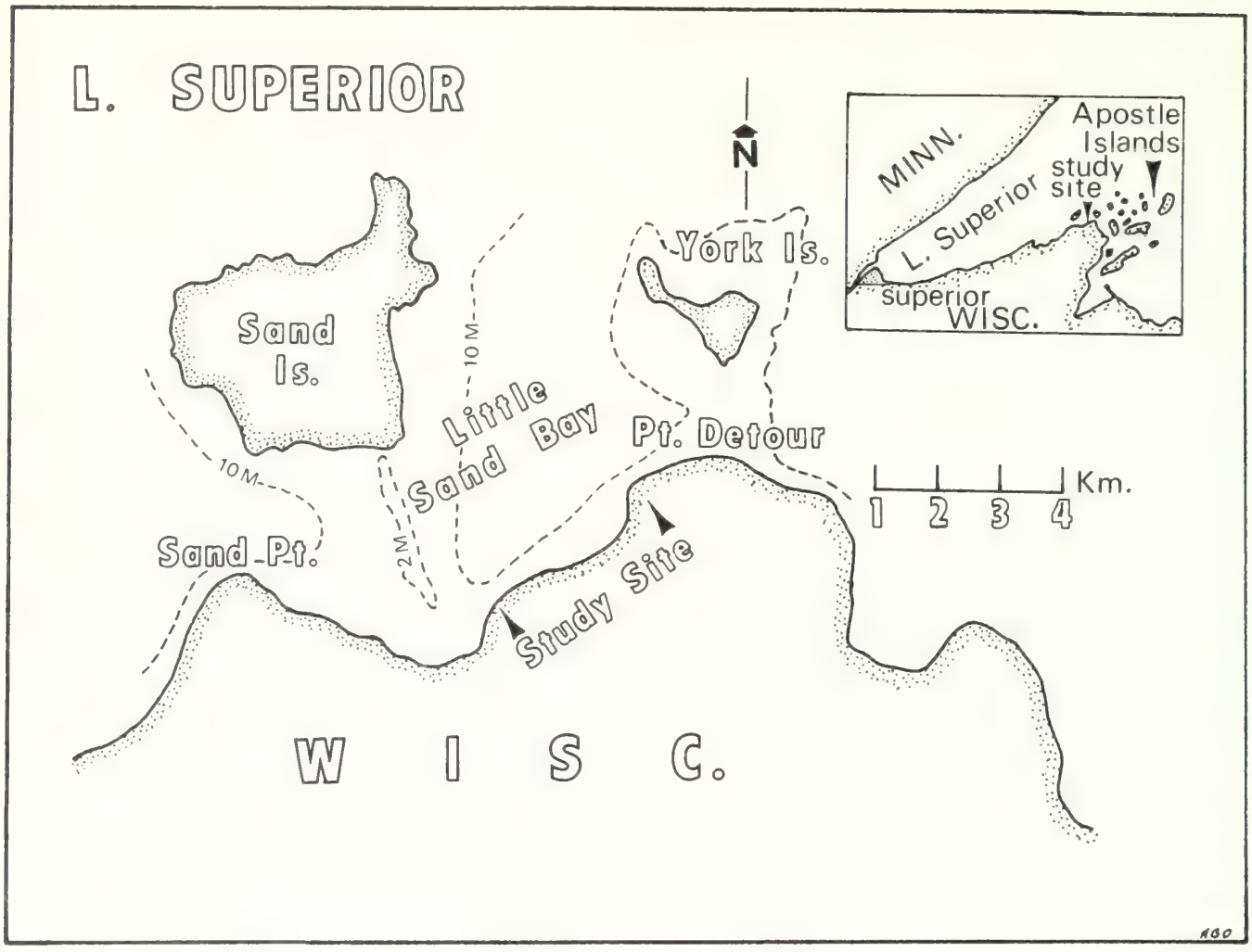

FIGURE 1. Study location and general morphology Little Sand Bay.

A similar submerged tombolo "attaches" York Island, located 1.5 km offshore to Point Detour. This tombolo has a minimum depth which ranges from 6.5 m near the mainland shore to 2.0 m near the island shore (Chart L.S. 96) and would have minimal effect on northeasterly storm waves.

The lake water levels at Little Sand Bay are relatively stable due to the control of Lake Superior water levels since 1921 by the International Joint Commission (IJC) through the International Great Lakes Levels Board. The present proposed plan of the IJC (termed SO-901) is designed to hold back water in Lake Superior during periods of abnormally high precipitation, for the purpose of preventing high water levels in the lower Great Lakes (International Great Lakes Levels Board 1973). In addition to this control, Lake Superior is subject to long-term, seasonal and short-term fluctuations.

Over the 115 years of recorded lake levels (since 1860), no regular or predictable cycle of water levels has been associated with this lake. The maximum recorded lake level range which has occurred over this period of years was 1.17 m (182.34 m low to 183.5 high) (NOAA 1974). Seasonal fluctuations are characterized by higher net supplies in the spring and early summer and lower net supplies in the remaining months. This magnitude of change averages approximately 0.30 m, characterized by the recordings for the first 6 months of 1974 where a range of 0.38 m was recorded at Duluth, Minnesota (NOAA 1974). Short-term fluctuations can be expected to last from a few hours to several days and are caused by various meteorological disturbances, such as water piled up at one end of the lake by wind (termed set-up), or differing barometric pressure (termed seiche), and tidal action. A maximum seiche of 2.1 m of differential between the eastern and western portions of the lake was reported by Gross (1972). NOAA (1974) reports that the maximum true tides effect for Lake Superior (combined solar and lunar) is less than 5 cm, which would have a minimal effect upon the study area.

Different sectors of the Little Sand Bay area were emphasized during the two phases of the study. Phase I, which monitored conditions until the winter ice-up, covered the western half of Little Sand Bay, a length of 695 m of sandy beach extending from the western sandstone cliffs to the eastern edge of the swamp mouth barrier. Phase II, which monitored postwinter conditions, covered the entire 1,305 m of beach from the western sandstone cliffs to the eastern till cliffs, emphasizing the eastern half. This division of emphasis allowed for observation of a one-year cycle in the area of the existing docking structure and reconnaissance of the entire bay for a suitable site for construction of a new harbor facility.

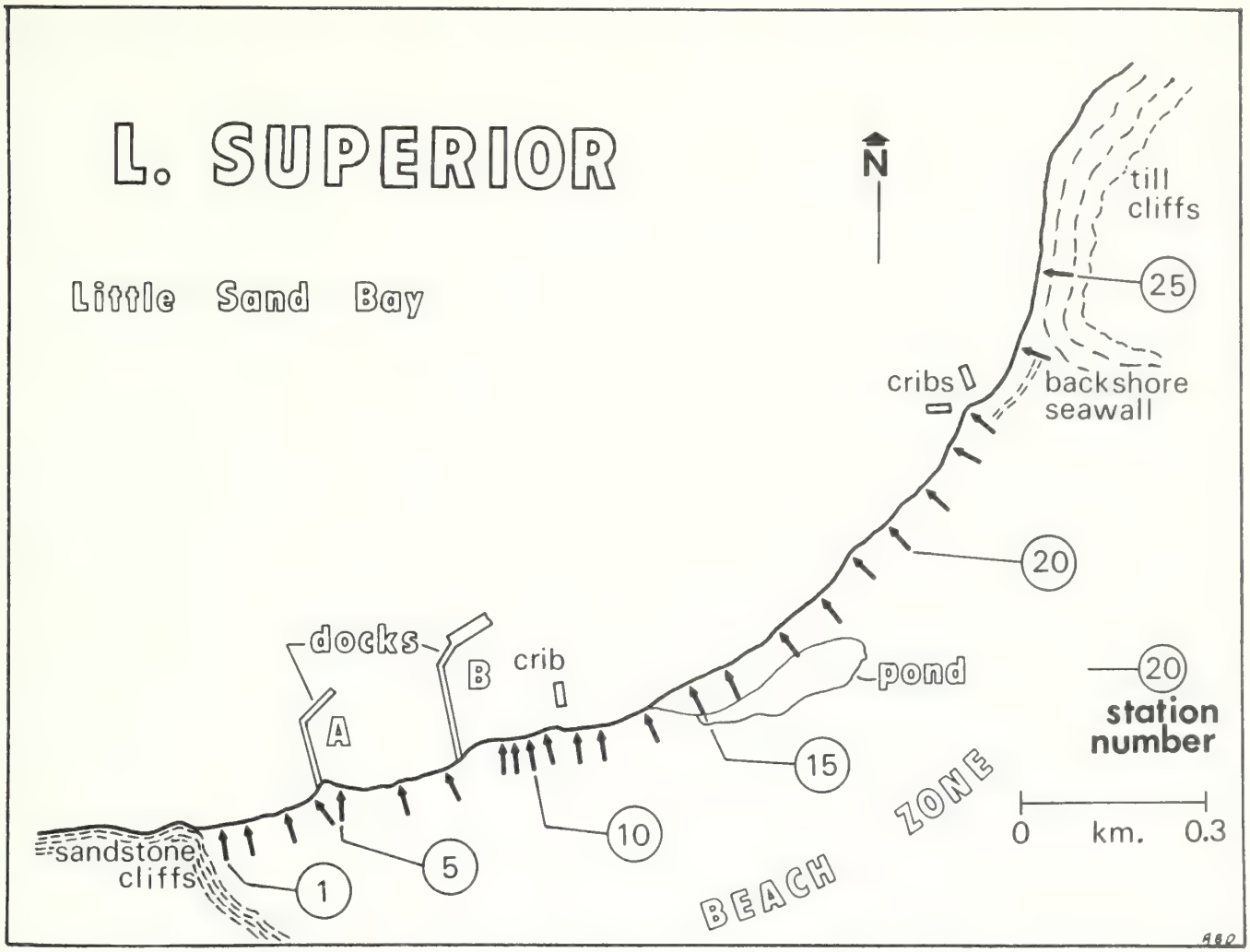

FIGURE 2. Station location and configuration of the study area.

DISCUSSION

Prior to the recommendations for a suitable harbor site and suggestions for general docking design, a summary of the baseline data obtained and the interdependence of the monitored coastal geologic parameters can be presented to further clarify the existing conditions in Little Sand Bay.

The general setting and morphology of Little Sand Bay are related to the relative protection and exposure of the coast to wave attack. The whole bay area is one of relative protection afforded by the location of Sand Island 3.2 km off the mainland and the direct relationship of Sand Island to the shallow, submerged sandbar which connects this island to the mainland. This setting blocks most of the dominant north-west waves, which have a possible 48 km fetch length. Proof of this protection lies in the fact that this 1.3 km stretch of shoreline is one of the few coastal areas of Lake (10%) which contains a significant sandy beach (U.S. Army Corps of Engineers 1969).

Figure 2 illustrates that on a smaller scale, the major portion of this beach is relatively open to local wave attack with the only protection being afforded by engineering structures. Protection from wave energy by the structures has both beneficial and detrimental effects upon the existing natural shoreline and its processes.

In the protected zones adjacent to the docks and cribs, there is an accumulation of fine sediment in response to both blockage of the easterly longshore drift causing deposition on the updrift or western side of the obstruction, and the projection of a shadow zone of lower energy allowing for a deposition of sediment in this artificial low-energy environment.

In the more exposed areas of the remainder of the bay, the sediment size is dependent upon the

wave energy of the location and the local source of sediment. Erosion occurs both on the downdrift or eastern side of the protective, obstructing structures and in response to the winter or high-energy cycle of a beach zone. Accretion also occurs in these areas, in the lower energy or summer cycle, if there has been no upset in the equilibrium of forces. Such an upset was found in the area of exposed beach between stations 18-22 (Fig. 2) where there was a summer trend toward erosion along the narrow portion of beach.

The cycle of beaches as described by Shepard (1973) explains most of the erosional and accretionary cycles of the subaerial beach, except for the exceptions; however, it also appears to be the major means of explaining the movement of subaqueous sediment. The offshore substrate of the bay was found to have a fairly smooth, relatively steep slope gradient divided into two provinces based upon a break in the gradient and a corresponding change in grain size: the more gradual slope lakeward of the 6 m isobath having finer sediment than the steeper grade shoreward of this depth. This is to be expected due to the observed wave-induced currents, which decrease with increasing depth. This is borne out by the findings of decreasing sediment size with increasing depth offshore.

The data gathered from the stake fields and fluorescent tracer analysis, along with the recovered current meter data, suggest movement which correlated to wave energy and direction in the form of migrating offshore bars. If Shepard's (1973) statement is correct, then these bars are formed from sediment migrating away from the beach face in winter conditions. The sediment which was removed from the beach face is then replaced during summer conditions by the onshore migration of these bars as found by Barjorunas and Duane (1967).

The movement of these offshore bars is a major concern in deciding upon the proper design and placement of any engineering structure. Neglecting this phenomenon can result in the shoaling problem observed at dock B (Fig. 2). The offshore shoal found to be lakeward of this structure in Phase I was observed to migrate inside the shadow zone of the docks in Phase II, causing considerable sedimentation within the docking area. Due to the manufactured low-energy environment within the docking enclosure, the natural processes lacked sufficient energy to either redeposit the sediment upon the beach or to remove the sediment offshore, and the shoal persisted, becoming shallower with each summer phase. Proper design and placement of the proposed dock should alleviate most of these problems.

RECOMMENDATIONS AND CONCLUSIONS

Prior to a discussion of environmental effects of various types of docking breakwater systems, the broader questions of site selection should be analyzed. A previous National Park Service study by Dickas and others (unpublished 1974) was performed to determine the environmental background of the Apostle Islands National Lakeshore headquarters site. It was concluded that existing roads would be used wherever possible to minimize any further impact of man's actions upon the environment. The use of the two major existing road systems within the Little Sand Bay area thus limit the docking site selection to within the following two areas: (1) the existing docking facilities between stations 3 and 12, and (2) the area in the eastern corner of the bay between stations 22 and 24 (Fig. 2).

The selection of these two possible areas was not made on the basis of land-based accessibility alone, although it was the major consideration in rejecting the shore areas of station 1 and station 25 beneath the precipitous cliffs at the western and eastern boundaries of the bay. The area between stations 13 and 19 has also been rejected as a suitable zone due to the delicate stability of the sand spit separating the open lake from the shore pond located here and the unpredictable nature of breaching of this spit by spring-melt waters. The area between stations 19 and 22 was rejected also due to the instability of this section of shoreline based upon the observation of an erosive trend along this narrow section of beach. Therefore, based upon coastal geologic observations, areas (1) and (2) mentioned above are most suitable for harbor facility construction (Fig. 2).

The first factor to be considered in the analysis of these two areas is that of offshore slope gradient. From the consideration of bathymetry, at area (1) the slope between 0 and 3 m of water depth is 1.8% and from 3 to 5 m is 1.9%, while at area (2) the 0 to 3 m gradient is 1.7% and from 3 to 5 m is 1.1%. On this basis, area (1) would have to be the more advantageous due to a natural 3-m depth existing closer (<165 m) to shore.

Area (1) also has an advantage over area (2) in the consideration of wave-energy distribution. The projection of the western headland of the bay (unnamed) offers a moderate amount of protection to area (1) against the prevailing northwesterly storms which concentrate their energy in the eastern corner of the bay at area (2).

The third, and possibly most important consideration, is that of beach stabilization. With an easterly trending longshore drift and the undernourished beach area to the immediate west (stations 19 to 22) of area (2), placement of a docking structure at this site could be advantageous. The easterly drift would allow beach accretion in the area to the west of the structure, stablizing this zone. However, extensive erosion of the unconsolidated glacial till cliffs to the northeast of this site would probably accompany the accretion due to the sediment starvation and high energy conditions observed at this site. The eroded material would, in all likelihood, be deposited immediately within the dock enclosure, in much the same way it accumulates inside dock B. However, the erosion and accretion at this site could be alleviated by a properly designed, docking-breakwater system; diminished accretion would reduce the need for dredging while diminished erosion would reduce the need for revetting.

The fourth consideration is that of substrate differences between areas (1) and (2). The larger boulder field found at area (2) would create problems in driving support pilings for a dock. This problem would not be encountered on the smooth sand bottom at area (1).

To summarize the recommendations on area choice, area (1) is more advantageous than area (2) for the following reasons:

1. Higher slope gradient between the 3 and 5 bathymetric contours.

2. Relatively lower wave energy due to protection by western boundary headland, incipient tombolo and Sand Island.

3. Elimination of engineering oriented problem of sinking pilings in a boulder-strewn area.

However, it must be noted that area (2) is a viable alternative based upon the data gathered during the summer phase of this study. The question of structural design of the harbor facility must be answered in general terms due to the lack of specific details about the capacity of the harbor. No quantitative data as to number of craft to be harbored, expected traffic or minimum depth requirement for the anchorage area are available. However, the suggestions for construction criteria are given as minimum values, any of which could be expanded with little impact upon the environment.

The first type of docking design to be considered is that of a floating form. This precludes any attachment to the substrate other than anchors. This structure, however, must be attached to the beach face and would probably interrupt the passage of the longshore drift with resultant downdrift erosion and updrift accretion. There would also be deposition attendant to the attenuation of wave energy by floating pontoons, thus causing a buildup of sediment within the shelter of the dock. The amount of this deposition would depend upon the degree to which this dock would attenuate wave energy, and therefore the degree to which it would also protect harbored craft. The more protection the greater the sedimentation.

It is doubtful whether this type of docking system would be economically feasible for this particular area due to the rigors of the winter season necessitating the lifting and storage of the structure each autumn and reemplacement each spring.

The second type of system is that of a solid or impermeable design such as rubble mound or interlocking steel. This, of course, would have the greatest effect upon the wave-induced currents and the transported sediment. The erosion and deposition regime would be similar to that described for the floating dock, but magnified tremendously due to the complete interruption of the longshore drift which maintains the sandy beach. Shore erosion on the downdrift side would continue to cut into cliffs and forest until the time when the shoal, deposited on the updrift side, extended around the lakeward limits of the structure and nourished the downdrift area. This drift would then fill in the area intended as a boat anchorage area.

The third type of design is that of a permeable, piling-supported structure. If the pilings were spaced sufficiently wide enough to allow passage of longshore drift, there would be no disruption to the natural processes or beach morphology. There would be a slight buildup of sediment near the pilings due to their attenuation of wave energy, but this sediment should ultimately be reworked by the relatively unobstructed wave-induced currents. However, as the unobstructed waves would be damaging to boats anchored around this structure, this design offers no protection to harbored craft.

A combination of an impermeable, shore-parallel breakwater and a pereable, shore perpendicular, connecting arm should offer both craft protection and little interference with the coastal geologic processes. The dock must be oriented with the permeable section on the western end of the breakwater to offer the most protected area for anchored craft and the breakwater must be in a minimum natural depth of 3 m of water. Regarding piling spacing for this combination dock, a minimum of 1 m distance between pilings was arrived at from observation of the existing pilings of existing docks A and B. Dock B had pilings spaced approximately 45 cm apart, which caused drift blockage. Dock A had pilings spaced approximately 75 cm apart, which caused little drift blockage. Therefore, a minimum figure of 1 m apart would be sufficient.

The 3 m minimum depth for the breakwater was estimated from the stake field and current meter data employed in these studies. There was minimal current activity at the 2.25 m deep station but none at the 5.0 m deep station. Also the magnitude of movement of the field in 3.3 m of water was much less than that of the shallower fields. Therefore, the 3-m limitation figure would allow space for shoal and bar migration which is most active in the 0- to 3-m depth range. This should alleviate the problem of dredging the anchorage area due to the lack of cessation of sediment motion in the deeper water resulting from the inaction of bottom currents.

In summary, a combination of an impermeable breakwater and a permeable walkway structure is the recommended design for this area for the following reasons:

1. Relative nondisruption of longshore and wave-induced currents with resultant beach stability.

2. Minimal impact upon near and offshore bathymetry.

3. Attenuation of storm waves and related protection to moored boats without disruption of near shore processes.

4. Minimization of dredging problems usually related to a harbor structure.

LITERATURE CITED

BAJORUNAS, L. 1960. Littoral transport in the Great Lakes. Coastal Engineering Proceedings, 7th Conf. 326-339.

_____ and D. B. Duane. 1967. Shifting offshore bars and harbor shoaling. Jour. Geophysical Research, 72 (#24):6195-6205.

BERG, D. W. 1968. Systematic collection of beach data. U.S. Army Corps of Eng. Coastal Eng. Research Center. Reprint 4-69.

BRUUN. P. 1955. Beach profiles and development of plans for coastal protection. College of Eng. Univ. of Florida, Gainesville. Bulletin Series No. 66.

_____ and M. Manohar. 1963. Coastal protection for Florida; development and design. College of Eng. Univ. of Florida, Gainesville. Bulletin Series No. 113.

DAVIS, R. A. and others. 1972. Comparison of ridge and runnel systems in tidal and non-tidal environments. Jour. Sed. Petrology. 42(#2): 413-421.

DICKAS, A. B. and others. Unpublished, 1974. Environmental survey, Little Sand Bay headquarters site, Apostle Islands National Lakeshore, Wisconsin. Center for Lake Superior Environmental Studies Contract Publication #29, 1-46.

ENGSTROM, W. E. 1974. Beach foreshore sedimentology and morphology in the Apostle Islands of Northern Wisconsin. Jour. Sed. Petrology. 44(#1):196-206.

GROSS, M.G. 1972. Oceanography, a view of the earth. Prentiss-Hall pub. 558 pages.

HAMBLIN, W. K. 1961. Paleographic evolution of the Lake Superior region from late Keweenawan to late Cambrian time. Geol. Soc. of Amer. 72:1-18.

HAYES, M. O. and others. 1973. The investigation of form and processes in the coastal zone. In Coastal Geomorphology, D. R. Coates, Ed. Proc.

3rd An. Geomorph. Symposia Series; Binghamton, N.Y. 11-41

HOUGH, J. L. 1958. Geology of the Great Lakes. Univ. of Illinois Press, Urbana, Ill.

INTERNATIONAL GREAT LAKES LEVELS BOARD. 1973. Regulation of Great Lakes water levels. Rept. to Internat. Joint Commission. 31-51.

LOY, W. G. Unpublished, 1962. The coastal geomorphology of western Lake Superior. M.S. dissertation, Dept. of Geography, Univ. of Chicago, 1-153.

NATIONAL WEATHER BUREAU. 1974. Summary of surface weather observations for Duluth, Minn. Data Processing Div. Nat. Weather Bureau, Asheville, N.C.

N.O.A.A. National Ocean Survey. 1974. Monthly and annual mean elevation of Lake Superior at Ontonagon, Michigan. U.S. Dept. of Commerce, Lk. Survey Center, Detroit, Mich.

SHEPARD, F. P. 1973. Submarine Geology. 3rd Ed. Harper and Row. N.Y., N.Y. 123-161.

U.S. ARMY CORPS OF ENGINEERS. 1966. Shore protection, planning and design. Coastal Eng. Research Center, Tech. Rept. No. 4. 1-562.

_____ 1969. Report on field investigations of high water damage and flood potential on the Lake Superior Basin. Dept. of Army, St. Paul Dist. 1-18.

_____ 1974. Great Lake shoreline; problems and solutions. Pamphlet printed by Dept. of Army, North Central Div. Chicago, Ill.

CASE HISTORY OF A COASTAL INVESTIGATION AT THE CAPE COD NATIONAL SEASHORE

Maurice L. Schwartz[1]

This paper is not a report on a recent or ongoing investigation, but rather an outline of research carried out at the Cape Cod National Seashore when it was newly established, and a tracing of what has happened to the findings of that research in the interim between that time and the present First Conference on Scientific Research in the National Parks.

In a short paper, Bruun (1962) had made a theoretical statement of beach erosion that would result from a rise in sea level. According to Bruun (see Figure 1), assuming a profile of equilibrium, following a rise in sea level:

a) There would be a shoreward (and upward) displacement of the beach profile as the upper beach was eroded.

b) The material eroded from the upper beach would be equal in volume to the material deposited on the nearshore bottom.

c) The rise of the nearshore bottom, as a result of this deposition, would be equal to the rise in sea level, thus maintaining a constant water depth in that area.

This statement was essentially intuitive, based on Bruun's many years of observation and experience, for it was unproven at the time by either laboratory or field measurements.

The first test of the validity of Bruun's theory was carried out utilizing a steam table at Columbia University in 1963. Results of this small-scale model test supported the statement, and the investigation report was published in the Journal of Geology (Schwartz 1965).

The theory was subjected to another small-scale laboratory model test in 1964, again at Columbia University. This time a somewhat larger wave basin was employed and considerably more experimental data was obtained. These observations supported the earlier laboratory tests and were incorporated into a second Journal of Geology report (Schwartz 1967). However, it still remained to find a suitable field model of sea level rise with which to test Bruun's theory.

The solution to this problem was soon found in the form of the bimonthly neap-spring tidal cycles. Utilizing the higher reach of the spring tide, as compared to the lower reach of the neap tide, there would be obtained an effective rise in sea level against which field measurements could be made.

In searching about for a suitable field site, mention was made of the Cape Cod shore. Besides having had a long and fond association with the beaches of the Cape, the Cape Cod National Seashore had just recently been established and it seemed to offer great promise as a place to conduct the kind of research that was envisioned in this project. Permission to work on the park beaches was quickly obtained from the park superintendent; a house was rented in nearby Brewster; and in the summer of 1964 the investigation was carried out by profiling at two beaches during low neap and low spring tidal stages.

The two beaches chosen were Herring Cove Beach to the north and Nauset Light Beach to the south (see Figure 2), selected as representing typical protected bay and open ocean beach environments respectively. Profiling was done at low tide stages in order to best take advantage of the greater foreshore exposure and nearshore bottom access at that phase of the tidal cycle. The profiling technique was a modification of the Emery (1961) method, subsequently dubbed the Schwartz One-man Beach-profiler (S.O.B.). The apparatus consisted of an aluminum frame with rigid upright and horizontal members, with a slotted guide for a vertical ruler at the unsupported end. Attached to the horizontal member was a bubble level, a compass, and a square plastic panel upon which notations could be made with a wax crayon. With this equipment and scuba gear (weighted for negative buoyancy), the investigator could profile from a monument on the beach, across the foreshore, and out onto the nearshore bottom. Figure 3 shows the profiles obtained in one neap-spring cycle. The total results of this investigation, together with the aforementioned wave basin data, were supportive of the Bruun statement and were subsequently published in an article that proposed the term, "Bruun's Rule," be applied to the theory (Schwartz 1967).

At this point, it is appropriate to discuss the role of the Cape Cod National Seashore in the investigation that has just been described. First of all, the two beaches proved to be morphologically suitable for the study at hand. Secondly, the park staff were most helpful and supportive throughout the summer investigation. This aid varied from permission to work there and advice about the region to aid in digging out my car when it became bogged down on a sandy road. A friendship was formed with one part-time summer ranger (a high school teacher in New England during the rest of the year) who presented illustrated slide talks on the beach concerning the geological evolution of Cape Cod. In more recent years this former ranger, John Maccini, now in the Earth Science Education Office of NSF, and I came together again as we became involved in the new Crustal Evolution Education Project (CEEP).

The research that has been outlined here was subsequently incorporated into the geologic literature and cited in a number of instances. One of the first of these was an article by Swift (1968) on coastal stratigraphy. Following that were discussions in both *Coasts* (Bird 1969) and *Beaches and Coasts* (King 1972). The Nauset Light Beach site was included as a notable stop, with tongue-in-cheek humor I suspect, in Fisher's field guide to the geology of the Cape Cod National Seashore (Fisher 1972). In a series of articles Dubois (1975, 1976) has verified and elaborated upon the Bruun Rule, utilizing his earlier investigations at Terry Andrae State Park, Wisconsin.

The acceptability of the Bruun Rule, as proposed, appeared to be pretty well-established

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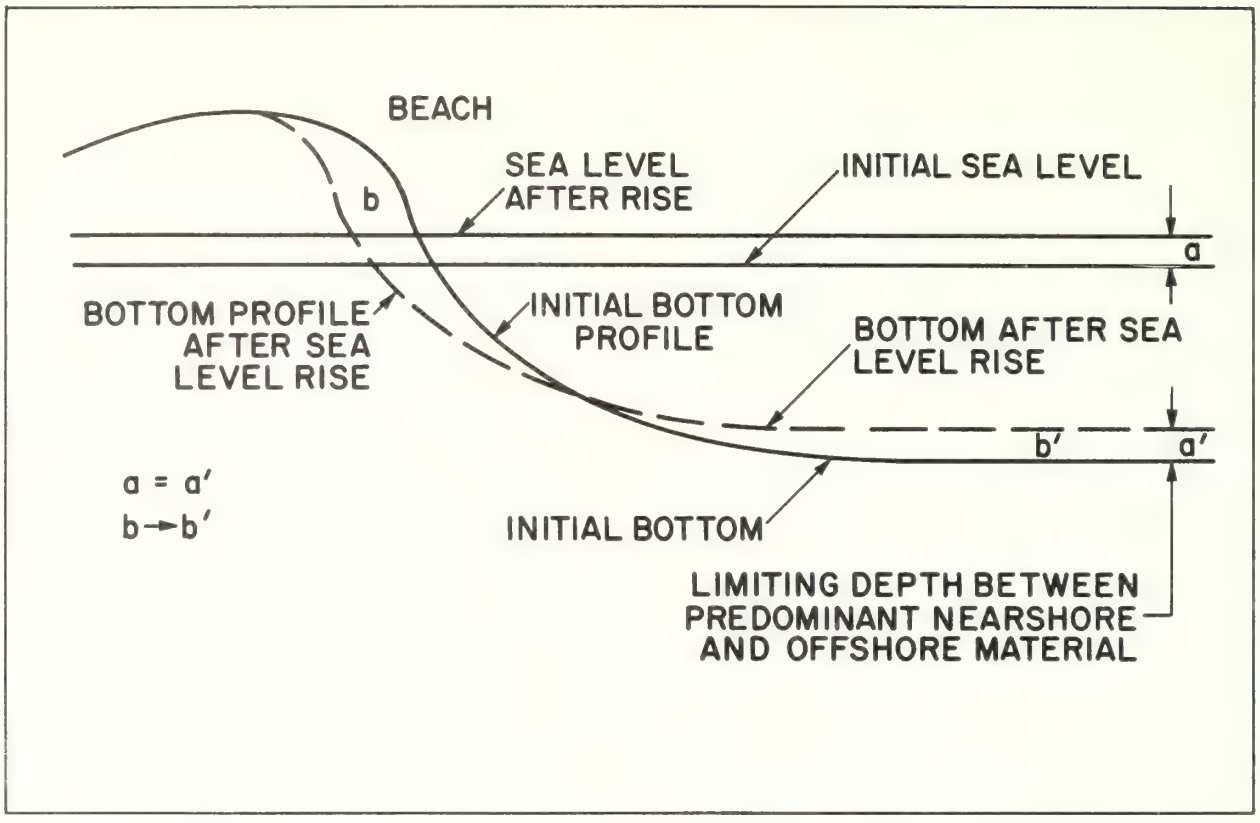

FIGURE 1. Shore erosion following a rise in sea level according to the Bruun Rule (after Schwartz 1967)

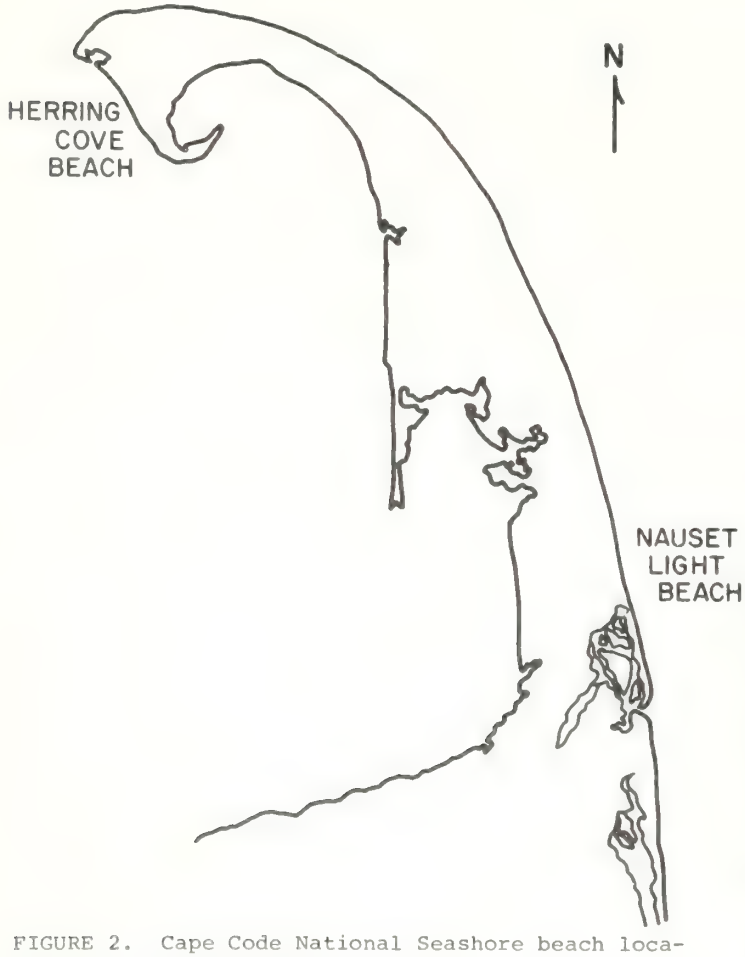

FIGURE 2. Cape Code National Seashore beach location map (after Schwartz 1967).

until recently, when the details of a book by Kaplin (1973) were brought to my attention. Kaplin (personal communication 1976) agrees with the relationship as put forth by Bruun, but holds that the first statement of the concept was made by V. P. Zenkovich (1958). In a translation offered by Zenkovich in a recent personal communication, it is evident that the first two points of the Bruun statement are covered there. Only the last item, concerning the correspondence of sea level rise and nearshore bottom aggradation, seems to be missing. Therefore, it appears that Zenkovich did predate Bruun on the essence of the concept, but that Bruun added a quantitative aspect to the theory.

Thus, the controversy rests, but in the development of the subject as we know it today, the Cape Cod National Seashore played an important part.

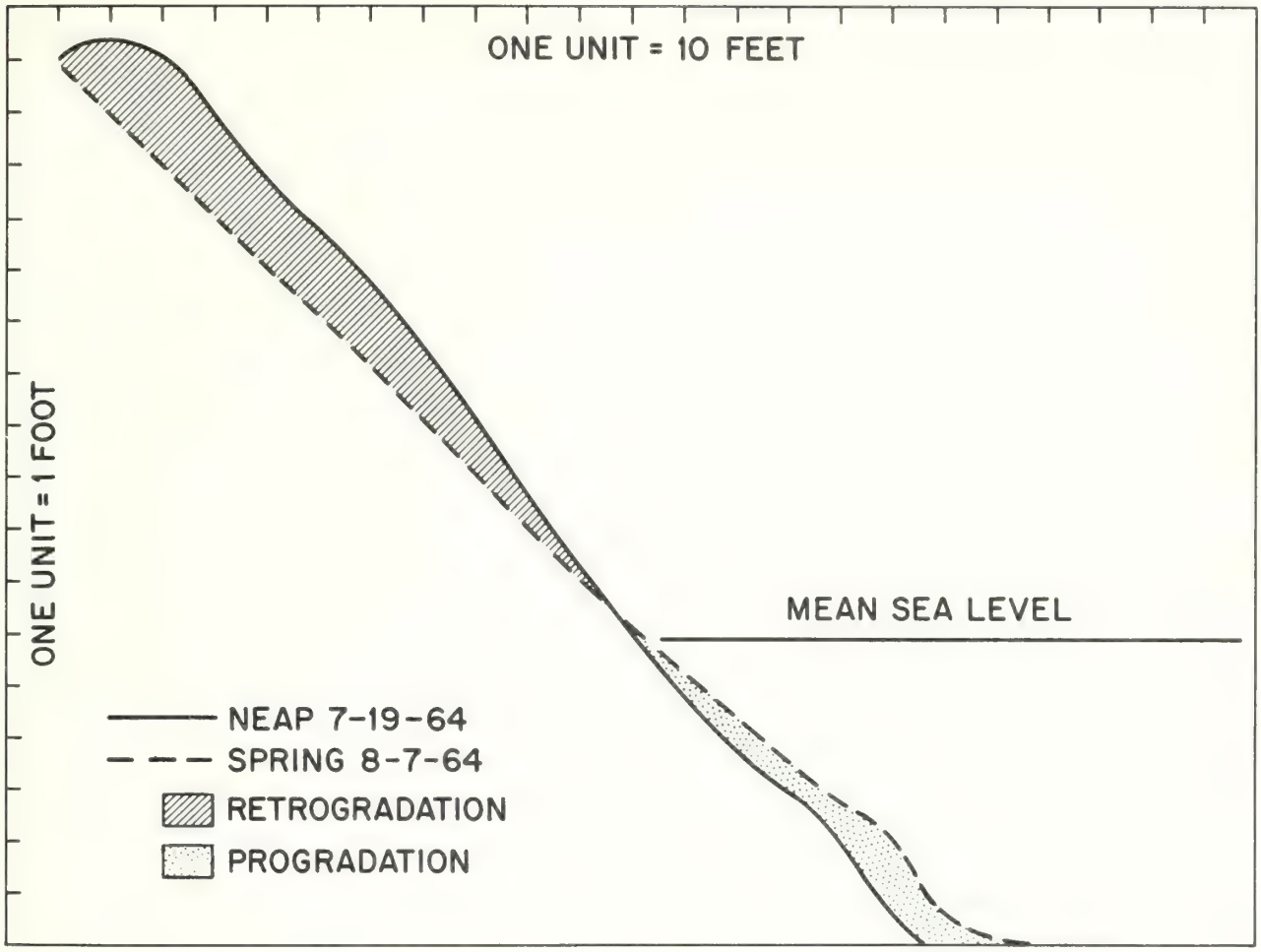

FIGURE 3. Nauset Light beach, neap-spring profiles.

LITERATURE CITED

BIRD, E. C. F. 1969. Coasts. Cambridge, M.I.T. Press, 246 p.

BRUUN, P. 1962. Sea-level rise as a cause of shore erosion. Jour. Waterways and Harbors Div., Am. Soc. Civ. Engineers Proc., 88:117-130 (also: Eng. Prog. Univ. Fla. Leaflet 152, 15 p.).

DUBOIS, R. N. 1975. Support and refinement of the Bruun Rule on beach erosion. Jour. Geology, 83:651-657.

_____, 1976. Nearshore evidence in support of the Bruun Rule on shore erosion. Jour. Geology, 84:485-491.

EMERY, K. O. 1961. A simple method of measuring beach profiles. Limnol. Oceanog., 6:90-93.

FISHER, J. J. 1972. Field Guide to Geology of the Cape Cod National Seashore. Kingston, Dept. of Geology, Univ. of Rhode Island, 53 p.

KAPLIN, P. A. 1973. Modern History of the Shorelines of the World Oceans. Moscow, Moscow University Press, 266 p. (in Russian).

KING, C. A. M. 1972. Beaches and Coasts, 2nd ed. New York, St. Martin's Press, 570 p.

SCHWARTZ, M. L. 1965. Laboratory study of sea-level rise as a cause of shore erosion. Jour. Geology, 73:528-534.

_____, 1967. The Bruun theory of sea-level rise as a cause of shore erosion. Jour. Geology, 75:76-92.

SWIFT, D. J. P. 1968. Coastal erosion and transgressive stratigraphy. Jour. Geology, 76:444-456.

ZENKOVICH, V. P. 1958. The Morphology and Dynamics of the Black Sea Soviet Coasts. Moscow, Ac. Sci. U.S.S.R. Publ. House, 186 p. (in Russian).

SPIT DYNAMICS AND MANAGEMENT PROBLEMS OF SANDY HOOK, GATEWAY NATIONAL RECREATION AREA

Karl F. Nordstrom[1], Norbert P. Psuty[1], James R. Allen[2], Lynn R. Sherman[1] and Jonathan R. Pawlow[1]

INTRODUCTION

Management of coastal resources demands a working knowledge of the natural system in which objectives are identified and strategies are to be applied. The Sandy Hook Unit of the Gateway National Recreation Area is presently the site of investigations that are directed toward an understanding of the coastal processes that are developing the geomorphologic parameters of the Hook. One of the objectives of the study is to produce a simulation model of the Hook that is based on its process-response characteristics. Given this model, it will be possible to simulate the effects of certain strategies or natural events that could change the physical conditions of Sandy Hook.

The shoreline of Sandy Hook (Figure 1) consists of seven distinct shore segments, as defined by differing processes and process intensities, and by different responses to these process functions. The net sediment migration is from south to north on the oceanside, and from north to south on the bayside.

The present goals of the management program for Sandy Hook are identified as follows:

1. retain the beach in the southern portion of the spit as the principal recreation area;
2. establish a limited access beach at the old Army recreation beach;
3. maintain wide berm surfaces and backbeach areas to maximize recreational use;
4. establish protected areas for wildlife; and
5. maintain the natural character of the entire Hook as much as possible.

Given these objectives, geomorphological inputs are required to characterize the mobility of the beach profile, to determine sediment budgets, and to predict the outcomes of the various beach management strategies. These strategies may range from allowing the natural system to run its course, to a beach nourishment program and its ramifications, or to a solid sea wall that will serve to stabilize the shoreline.

THE SPIT MODEL

Broadly, the research program is a study of the dynamics of the spit. Specifically, the studies focus upon the dynamics of the various beach segments and the amount of interaction between them. Through the process of combining the studies of the individual compartments, it will be possible to synthesize the information into a general model of the entire spit. With this objective, several projects are underway. These include:

1. a historical analysis of shoreline change utilizing long-term survey data and short-term aerial photography;
2. a hydrodynamic study of the waves, longshore currents, tidal currents, and wind effects on the various segments;
3. sediment mobility studies of inter- and intra-segmental movement;
4. monitoring morphologic changes to include the rates of establishment of storm profiles and equilibrium forms.

Data and analyses from these projects are being combined to develop a mathematical computer model capable of simulating the refraction of wave trains, of calculating wave energies and sediment movement, and of projecting this into shoreline responses. This model is present in diagrammatic form in Figure 2. Through refraction analysis, wave spectra will be converted to energy vectors which may then be used to compute the direction and rate of flow of currents and the sediments they move. The eventual correlation of wave data with sediment flow and beach form changes will yield stability values for the various beach segments. The model will then be used to predict shoreline changes that will be produced by man-made or natural events.

It is reasonable to assume that a simulation model of Sandy Hook will be valuable in providing an objective assessment of the many choices for shoreline defense or enhancement. Further, use of the model will entail great savings in time and effort vis-a-vis extended field studies. It will represent an overall synthesis of spit dynamics and it will also be able to replicate the dynamics of the individual beach segments. Whereas, each of the subroutines is based on state-of-the-art theory, the all-important coefficients must and will be generated from the local field studies instead of using the existing approximations derived from such diverse environments as laboratory wave tanks and Pacific coast beaches.

In the hydrodynamic portion of the model, linear wave theory is used to refract wave rays of specified characteristics to the shoreline over a bathymetric grid. Sample wave refraction output is presented in Figure 3. The values depicted represent concentrations of energy in the zone of breaking waves. The energy value is unity in deep water. Therefore, the values at the shoreline depict the relative concentration or diffusion due to refraction. One set of wave conditions is represented as approaching from the east with a deep water wave height of four feet and a wave period of eight seconds (Figure 3A). These characteristics are near the mean storm conditions for oceanside beaches. Waves approaching from the northwest associated with cyclonic storm conditions are represented by two-foot waves with a three-second period (Figure 3B). These characteristics are near mean storm conditions for bayside beaches. The wave parameters which are input

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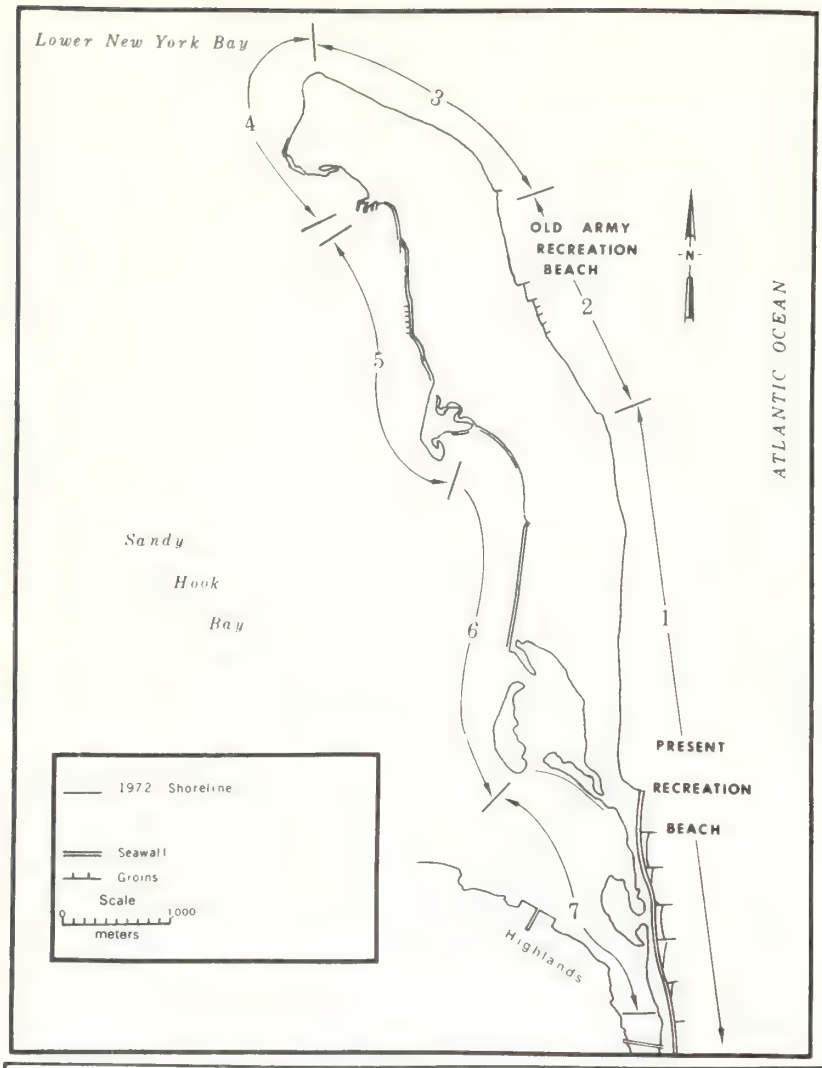

FIGURE 1. Sandy Hook, New Jersey, and its division into shoreline segments.

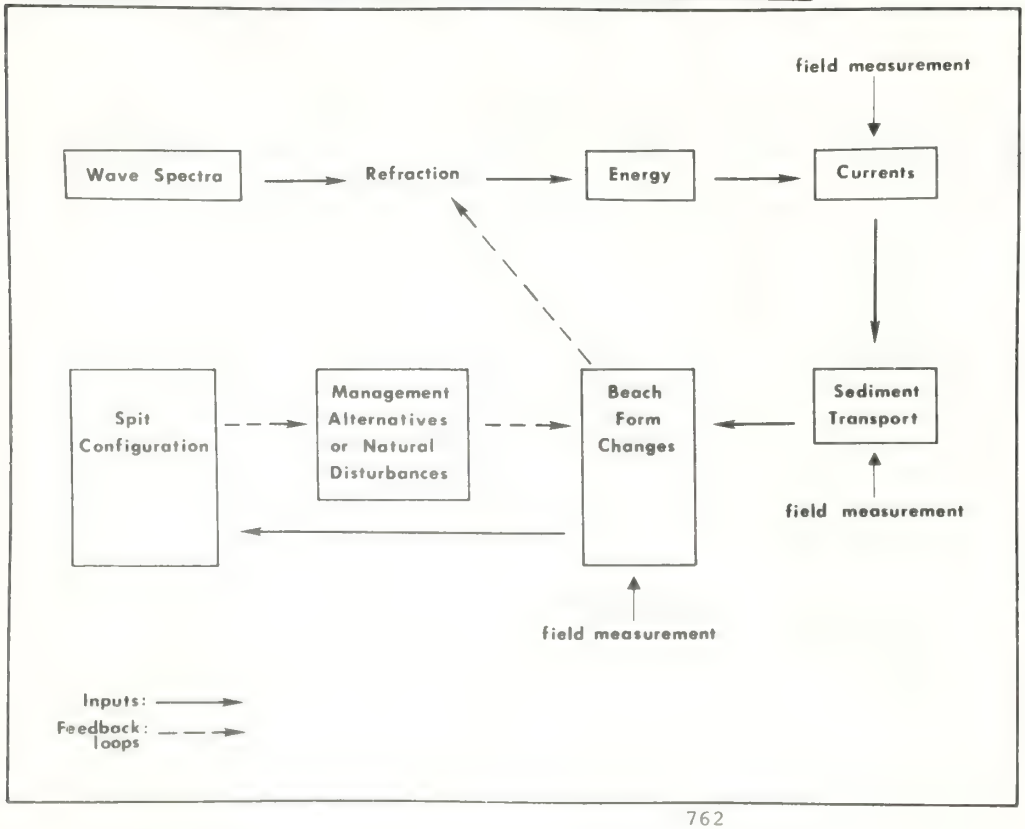

FIGURE 2. The management model.

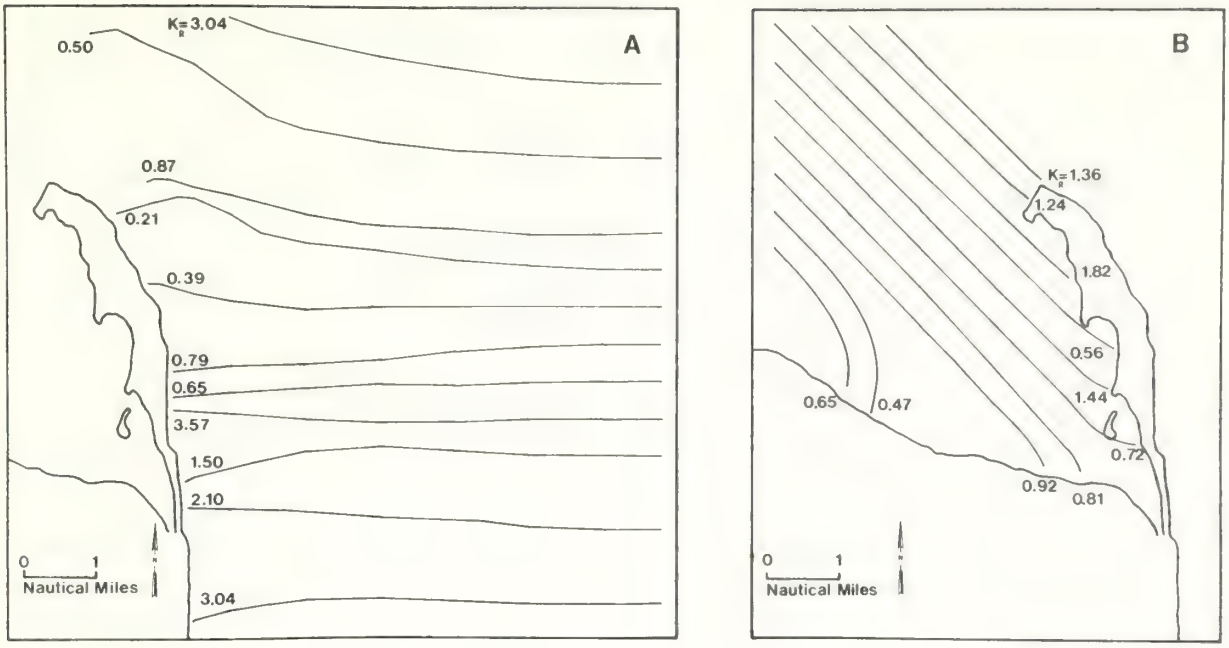

FIGURE 3. Sandy Hook wave refraction model.

to the model are wave height, wave period, and direction. They may be provided by wave hindcasts of actual events, real offshore wave observations from the edge of the grid such as at Ambrose Light, or from larger scale refraction studies that extend the waves in from true deep water conditions.

The wave rays are advanced in a series of steps over a smoothed surface. Once the shoaling wave height is equal to or exceeds 0.78 times the depth, the wave is allowed to break. The refraction plots show that the Sandy Hook wave climate does result in concentrations and diffusions of wave energy along the spit that correlate well with the present understanding of the shoreline dynamics. There is a decided concentration of wave energies in the southern portion of the spit (Figure 3A) near the present bathing beach where the high wave energies have contributed to the rapid retreat of the shoreline.

FIELD WORK

Wave Data

Wave observations have been conducted at numerous locations on the Hook (Figure 4). An analysis of the summarized wave data (Table 1) indicates that the mean breaker height varies in accordance with the energy coefficients identified in Figure 3. Overall there is a decrease in observed breaking wave heights northward along the oceanside and southward along the bayside for given wave trains. This is a function of wave refraction and it is accompanied by a similar decrease in wave energies, longshore currents, and sediment mobility. The field data support the concept of a gradient of wave energies as indicated by the refraction diagram. Further, the observations show that there are significant differences between adjacent segments. These data are being used to establish intersegment coefficients that will be incorporated in the predictive model.

Currently the programming involves the computation of the wave energies, longshore current velocities, and the expected sediment transport rate for each wave ray. The next subroutine to be developed will consider the shoreline as a series of small, contiguous beach cells. Longshore transfers from one cell to another can thereby be viewed as either a surplus or deficit, depending on the calculated value for the downdrift neighbor. This surplus or deficit is then translated into an amount of shoreline movement when the profile dynamics of the cell are known. Comprehensive studies of beach processes and responses within each segment have been gathered over 40-day time periods in the winter season on specific sites (Figure 4) to detail the effects of the storms on the beach profiles and determine the rates of return to a lower energy equilibrium. Additionally, certain storms, such as hurricanes, are individually targeted because of low recurrence probabilities.

Isolated Storm Events

The effects of Hurricane Belle were monitored this summer. This hurricane did not pass directly over the New Jersey shore, but it passed sufficiently close to Sandy Hook to cause some beach erosion. This erosion, indicated in Figure 5 (Case A), was of approximately the same magnitude as that which occurs during the passage of a small winter storm (Figure 5 Case B). The greater storm surge associated with the hurricane resulted in wave effects higher on the beaches than would be expected for a small winter storm, and a greater amount of dune overwash occurred.

The main recreation beach, which accommodates the largest number of beach users, experienced the greatest amount of overwash. Here, approximately 15,000 cubic yards of sand were washed over onto the parking area. The effects of this storm surge were also critical on the bayside beaches where the rise in water level allowed portions of the dune to be attacked. On some oceanside beaches, overwash resulted in a higher storm berm and thus increased the protection against future flooding and overwash. Foreshore erosion was prevalent, however, and in some segments there were no mitigating beneficial effects of the storm. None of

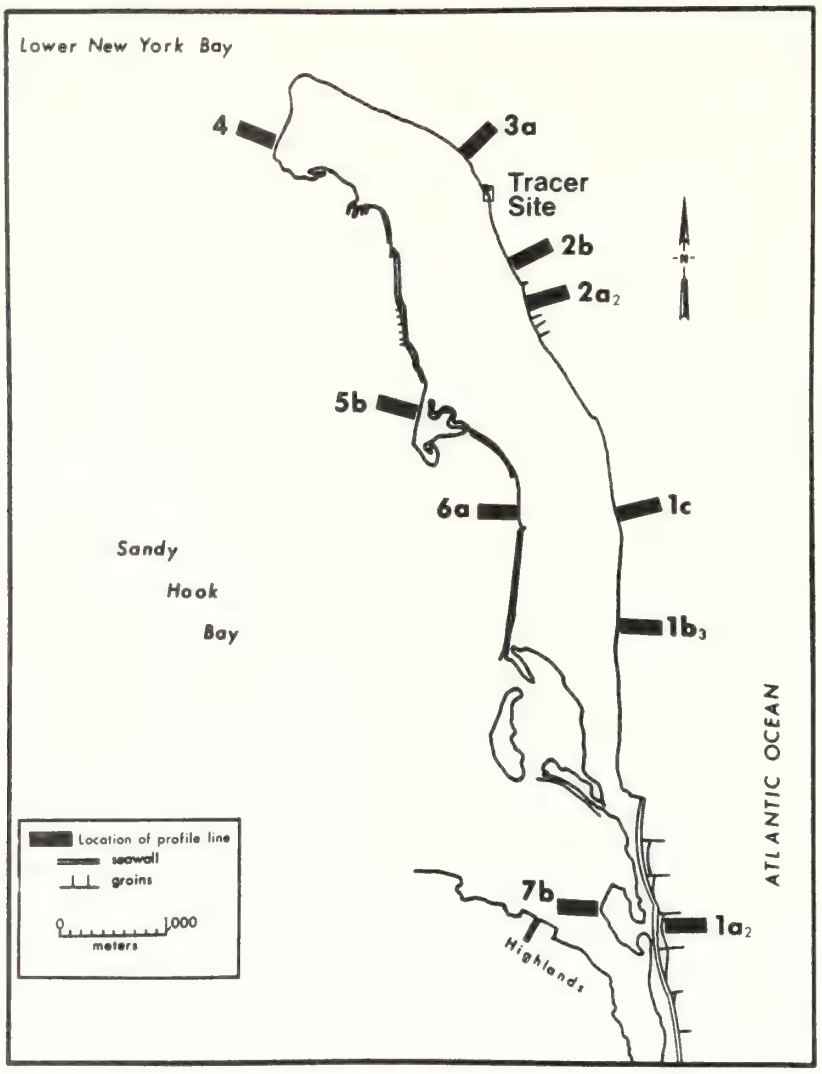

FIGURE 4. Location of data collection sites.

the storms monitored this year by the research group could be considered as high or even as moderate-intensity storms, and thus it should not be inferred that high-intensity storms would have similar effects.

Time-Series (Cyclic) Studies

The cyclic studies will provide the hydrodynamic variables for each beach segment which are used to specify the dynamics of each shoreline compartment, to refine existing beach theory, and to provide empirical coefficients for the simulation model. Figures 6 and 7 identify those changes associated with the passage of a mid-latitude cyclonic storm. Profiles taken at Site la (Figure 6) depict the cyclic form of beach development typical of high energy beaches. A considerable quantity of sediment is removed from the beach during the day of the storm as seen in the comparison of the profiles for 3/16 and 3/17. Thereafter, deposition occurs primarily as a swash ridge which migrates gradually up the foreshore. Wave energies are high on this site, and the migration of the swash ridge is rapid.

It appears that alongshore features, whether they be offshore bars or breakwaters, have the

TABLE 1. Average breaking waves statistics for sample sites identified in Figure 4.

Variable (and unit)	$1a_2$	$1b_3$	1a	$2a_2$	2b	3a
Days of observation	40	121	40	102	15	40
Breaker period (seconds)	9.4	9.7	8.9	9.4	9.8	5.9
Breaker height (meters)	0.67	0.82	0.64	0.58	0.55	0.27
Breaker angle (degrees)	9.7	7.9	13.5	10.2	9.6	11.3
Breaker steepness (H/L*)	0.005	0.006	0.006	0.005	0.003	0.005

	3b	4	5b	6a	7b
Days of observation	25	109	106	64	52
Breaker period	7.6	3.9	3.6	2.4	2.2
Breaker height	0.43	0.21	0.18	0.10	0.06
Breaker angle	12.2	11.1	5.7	9.0	16.0
Breaker steepness	0.005	0.013	0.013	0.010	0.007

*Breaker height/deep water wave length.

effect of reducing the energy of both erosional and depositional waves, thereby diminishing cyclic development. This theory holds for Site 3a (Figure 7), which is protected by the subaqueous spit extension from Segment 2. Cyclic development was absent on this beach during the same storm period, as revealed in the figure.

Despite erosion, there is an equilibrium of slope on Site 3a. The relative absence of beach change on this site is noteworthy, considering the rather large transfers of sediment which are moved periodically from Segment 2 to Segment 3 along the subaqueous segment extension. It is clear that beach sedimentation is a complex interaction that cannot be totally defined by profile form changes alone. Therefore, sediment trap and tracer studies are being employed at critical locations.

Sediment Trap and Tracer Studies

Fluorescent tracer experiments are presently being conducted to study the influence of groins and longshore bars on near and foreshore drifting over a tidal cycle. One such study was conducted within the groin field at the prominent break in shoreline orientation which separates Segments 2 and 3 (Figure 4). The purpose of this study was to determine the contributions of sediment movement along the foreshore and identify some of the complications induced by groins.

A grid of collection points (Figure 8) was set up prior to injection of the tracer, and after surf conditions and the dominant direction of littoral currents were observed. The figure shows the relationship of the sampling grid to the bar, which is the beginning of the segment extension, and to the groin field.

Figure 9 shows the movement of yellow tracer injected on the bar during the rising tide and it is introduced to show the nature of the information derived from the experiment. The results are that although there is a general migration of bar sediments shoreward in the breaker zone, there is little transfer from the bar to the foreshore. This indicates that most of the sand on the bar moves along the segment extension seaward of Site 3a. Unfortunately, the tracer technique identifies only the net directions of movement, not the discrete paths, and volumes of sediment moved cannot be accurately computed.

Accordingly, a sand trap study has been initiated to more accurately determine transport rates in offshore and longshore directions. This program is being conducted to develop quantitative values for sediment transport curves for both storm and non-storm conditions along Sandy Hook.

CONCLUSIONS

The development of the simulation model is a very useful tool for the park managers who are trying to balance recreational use with the maintenance of the natural setting. The model should be able to provide an objective assessment of the long range and short range effects of either allowing the natural system to run its course or of applying alternatives such as beach fill, groins, breakwaters, or shallow water dredging. Further, it will be possible to recommend strategies if specific goals are identified. Most importantly, the model will be an asset to management of the Sandy Hook Unit of the Gateway National Recreation Area because it will support the process of decision-making with sound scientific reasoning.

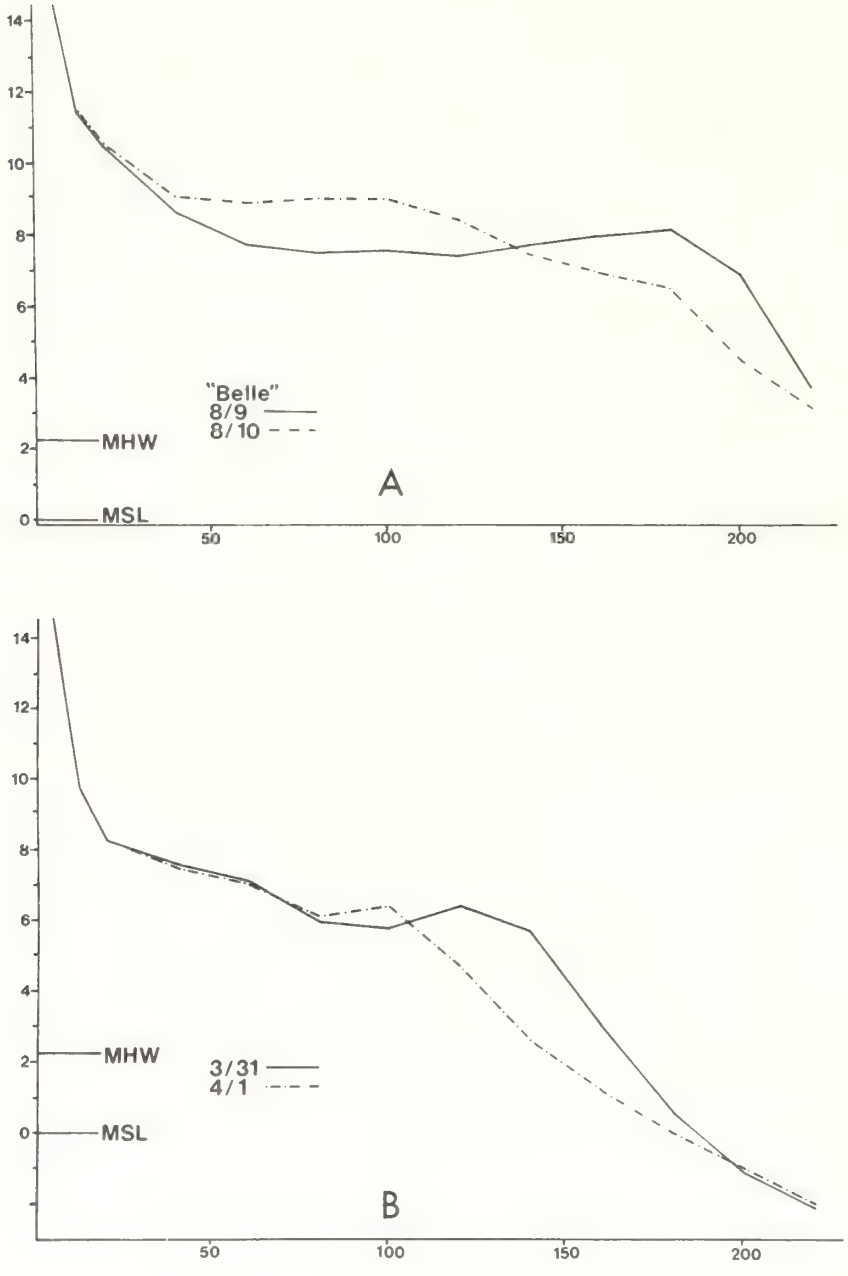

FIGURE 5. Storm effects on beach site 1C.

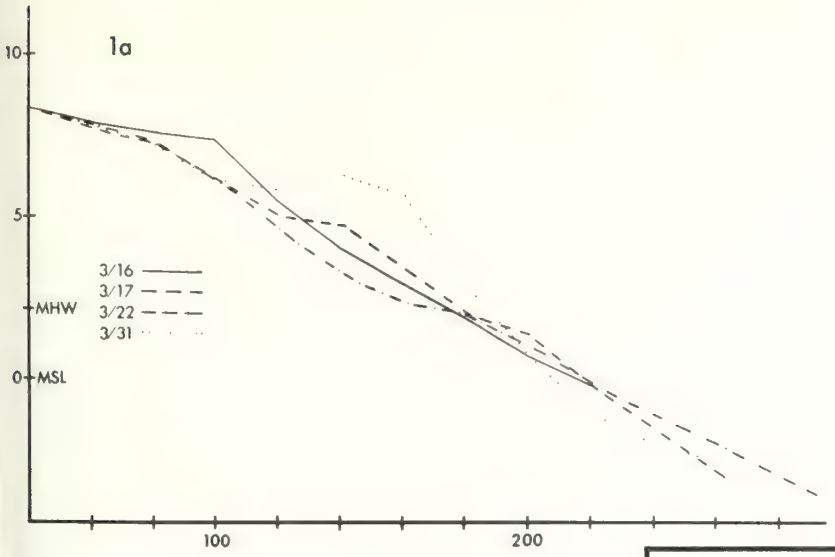

FIGURE 6. Storm effects on site $1a_2$.

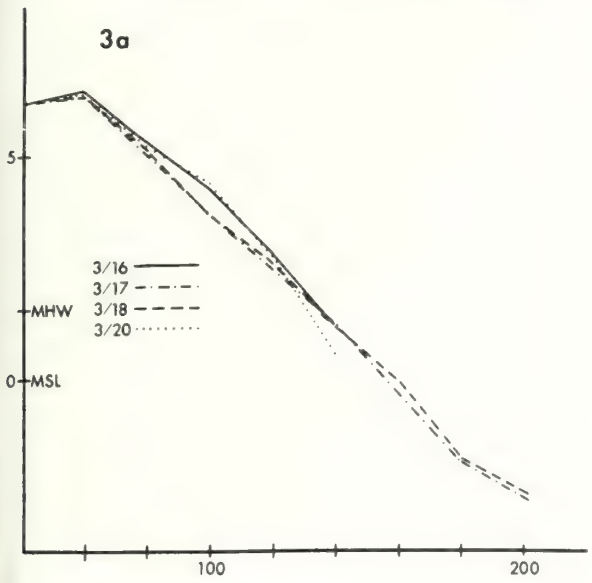

FIGURE 7. Storm effects on site 3a.

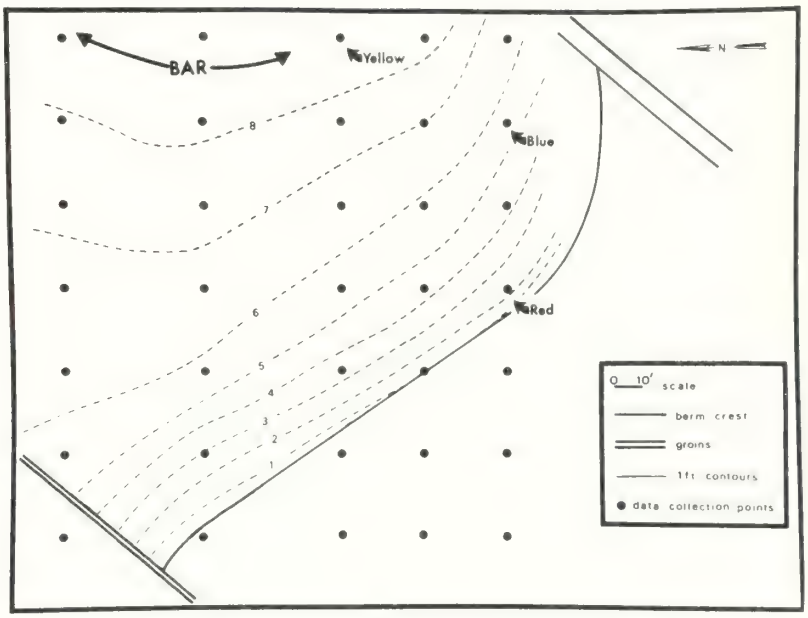

FIGURE 8. Sampling grid for tracer study.

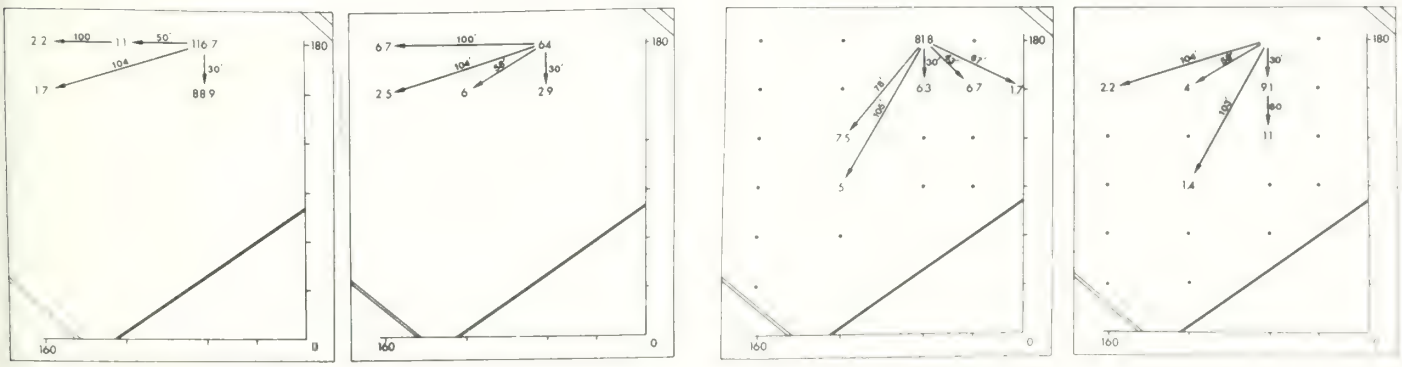

FIGURE 9. The movement of yellow tracer.

ASSATEAGUE ISLAND: A CASE STUDY OF BARRIER ISLAND DYNAMICS[1]

Stephen P. Leatherman[2]

INTRODUCTION

Recently there has been a recognition among coastal investigators as well as planners and administrators of the dynamic character of barrier islands. Overwash processes and inlet dynamics play a major role in the inherent instability of barrier beaches. The ecological response to overwash has been documented by Godfrey (1970) and Travis (1976) from their work on the Outer Banks of North Carolina. The short-term sedimentary dynamics and geological implications of overwash processes have only been hypothesized.

Overwash is defined as the continuation of swash surges over the most landward (storm) berm. Where primary dunes exist, the surges are funneled through breaches in the dune field (Fig. 1). This process results in the transport of seawater and associated sediment to the backdune area.

Assateague Island is a 33 mile long barrier along the Maryland and Virginia coast (Fig. 2). The National Park Service manages the northern one-half of the island as a National Seashore while most of the Virginia portion is controlled as a National Wildlife Refuge. The northern five miles of this island are presently eroding and subject to overwash during storm conditions. This investigation was designed to address the question of the importance of overwash in terms of the short-term sedimentary dynamics by field studies as well as the long-term significance as determined by aerial photographic techniques.

FIELD METHODOLOGY

Five survey sites were selected along this northern sector of the island (Fig. 2). These sites were surveyed monthly as well as prior to and after each major storm. Sites 1, 2 and 5 were established in distinct fan-type washovers whereas Sites 3 and 4 were located on the barren washover flats. Site 5 washover fan was quite large with a throat width of 200 feet and extending 800 feet landward from the front of the barrier dune (Fig. 3). A comparison of the scale of these washover features to the general morphology of the island gives the impression of the dominance of overwash processes along this coastal sector.

Profile lines were extended from ocean to bay across the island at the narrower reaches. At Site 1, a rectangular grid was superimposed over the entire area, including the washover fan, adjacent dunes and barrier flats (Fig. 2). The purpose of this detailed surveying plan was to quantify the redistribution of the sand on the fan surface.

SEDIMENTARY DYNAMICS

During the 26 month study (February 1973-April 1975), there were seven discrete overwash events. Only four of these storms resulted in any appreciable amount of overwash deposition. Storm parameters and sediment transport volumes are given elsewhere by Leatherman (1976a). For this paper we will only consider the December 1, 1974 northeaster which was the largest storm recorded during this time interval. In fact, this extratropical storm was the largest one to attack these shores since the Ash Wednesday storm of March 5-9, 1962. Profile changes at Site 1 will be used to illustrate those changes experienced at all sites. There was over 200 ft^3 of overwash deposition per foot of dune breach (Fig. 4). The beach was severely eroded for 100 ft^3 per foot of shore for the first 60 feet seaward of the dune line. Therefore, this storm resulted in large-scale displacement of material.

For sediment budget calculations, it is important to consider eolian processes. Field observations indicated that a large amount of overwash sand was transported back to the beach by the wind. Sand streamers, which were wind-shadow dunes, were found to point toward the beach, in the direction of sediment movement (Fig. 5). Meteorological data showed that there was a strong component of wind velocity from the northwest quadrant during the winter months.

The net 26 month change data yielded some surprising results. There was a loss of material even after seven discrete events as shown at Site 1 (Fig. 6). All other sites along the island exhibited a similar response pattern except where the sand was deposited at watertable level near the bayshore. These calculations indicate the nature of the short-term dynamics of washover areas, but the long-term perspective was needed to make a true assessment of this process.

BARRIER MIGRATION

The geological significance of the overwash process and inlet dynamics can best be assessed by considering long-term shoreline changes. Comparison of historical charts, maps and photography by the Maryland Geological Survey (unpublished data) showed the influence of Ocean City inlet jetties on the shoreline (Fig. 7). This shoreline was eroding prior to inlet stabilization in 1935, but since that time, the rate of erosion has increased to an average of 35 feet per year. The northern tip has migrated more than its width landward during this time period. Historical aerial photography must be used in order to determine the exact mechanism of barrier migration since charts and maps only delineate the shoreline position.

Aerial photographs from 1949 to 1974 were used to analyze the shoreline changes. The photographs were enlarged on a K & E Kargl Reflecting Projector to the common scale of 1:5,000. The high water line was chosen as the indicator of the land-sea interface after Langfelder, et al. (1968). Shoreline changes can be determined with an accuracy of several feet (Stafford 1971), depending upon the resolution of the imagery.

From the December 1974 imagery, it can be seen that there are four large accretionary lobes on

[1]This study was supported in part by the Office of the Chief Scientist, Mid-Atlantic Region, National Park Service, Philadelphia, Pa

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FIGURE 1. Overwash surges crossing the barrier threshold through a breach in the primary dune.

the bayshore (Fig. 2, lettered A,B,C and D). The origin of these depositional features can be determined since they did not exist prior to 1949. The lobes represent sites of temporary inlets and subsequent flood tidal delta formation as shown on Fig. 8 for three of the areas. The effectiveness of overwash in terms of bayside accretion and hence landward barrier migration can also be determined from the historical photography.

After the great Ash Wednesday Storm of March 5-9, 1962, the overwash penetration stopped short of the bay along most of Assateague. This northeaster is considered to be at least a 100 year storm, but yet it only resulted in landward migration along the most northern reaches. Here the amount of bayshore accretion almost equaled the amount of seaside beach erosion. For example, just north of Site 5 (Fig. 9), the average rate of change over the 25 year interval has been 27 feet per year for both shorelines.

By incorporating all shore data, it appears that the overwash process is only effective in maintaining an island's width within the limits of 400 to 700 feet (Leatherman 1976b). The isl will not narrow to less than 400 feet, since at this point, overwash is effective in transporti enough material over the island to compensate f shoreline losses. If the island's width exceed 700 feet, then bayshore overwash deposition wil not be able to keep pace with concurrent shorel erosion. Much of the material transported by t overwash surges would be deposited short of thi critical distance with little sand actually rea ing the bayshore.

CONCLUSIONS

The short-term sedimentary dynamics of a was over area indicated the balance between overwas and eolian processes. The washover fan/flats serve merely as a temporary reservoir for the eventual redistribution of the sediment by the wind. Sand transport by wind is not as dramat as storm-generated overwash, but this process continuous over a long time period.

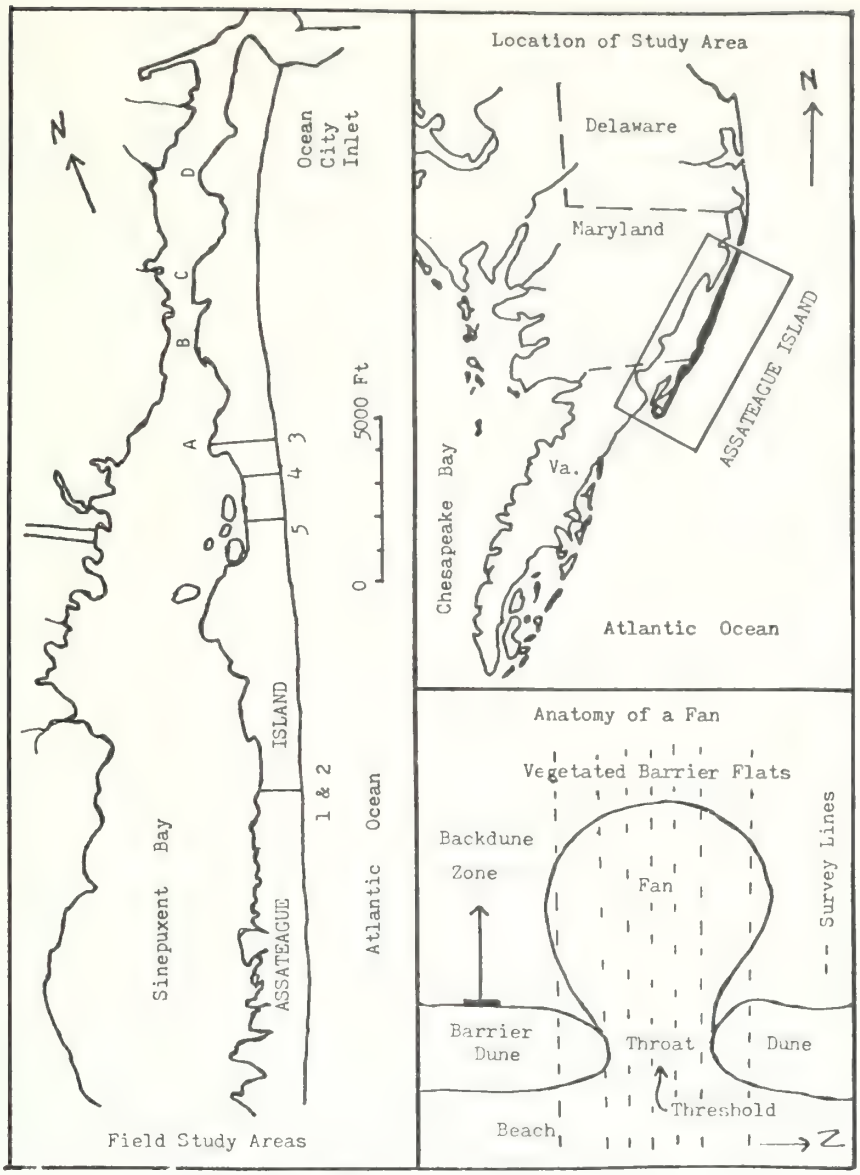

FIGURE 2. Location and site maps.

FIGURE 3. Site 5 washover fan in center and end of barrier dunes to the right.

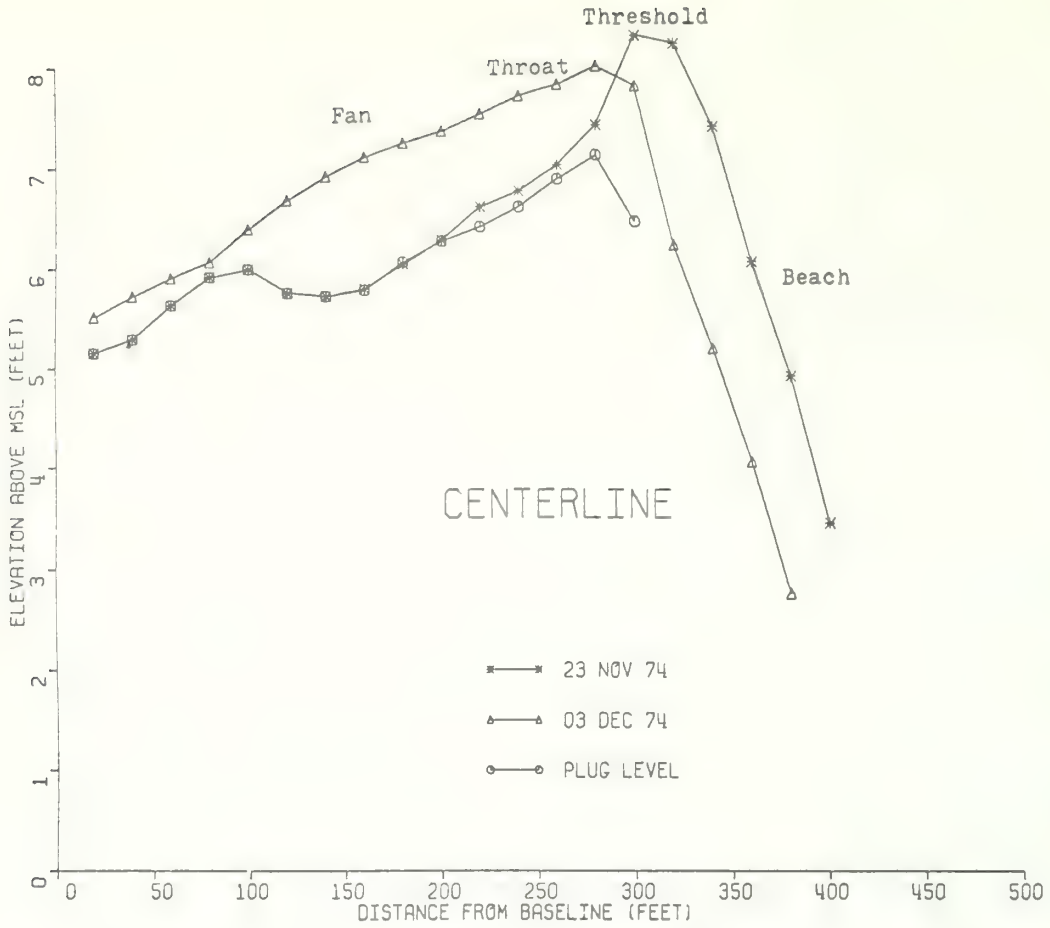

FIGURE 4. Site 1, centerline changes, December 1, 1974, northeaster.

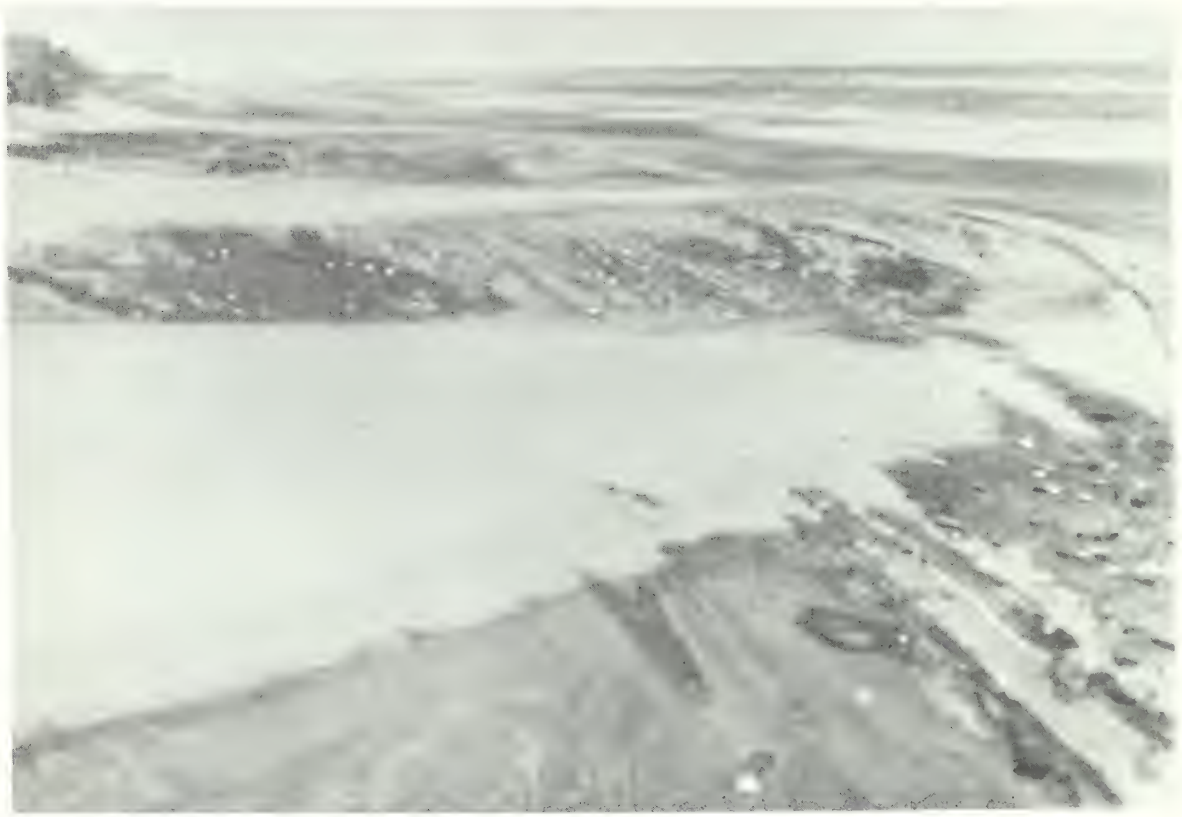

FIGURE 5. Wind shadow dunes pointing to the ocean with dune line to the left.

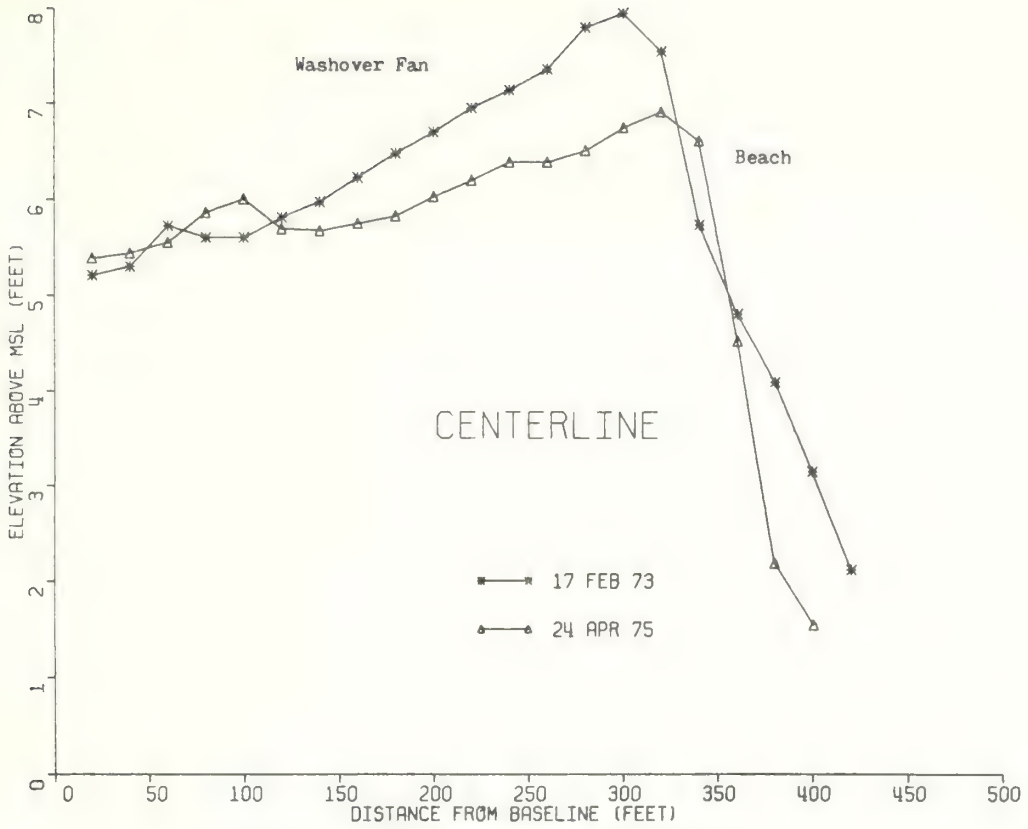

FIGURE 6. Site 1 net 26 month changes.

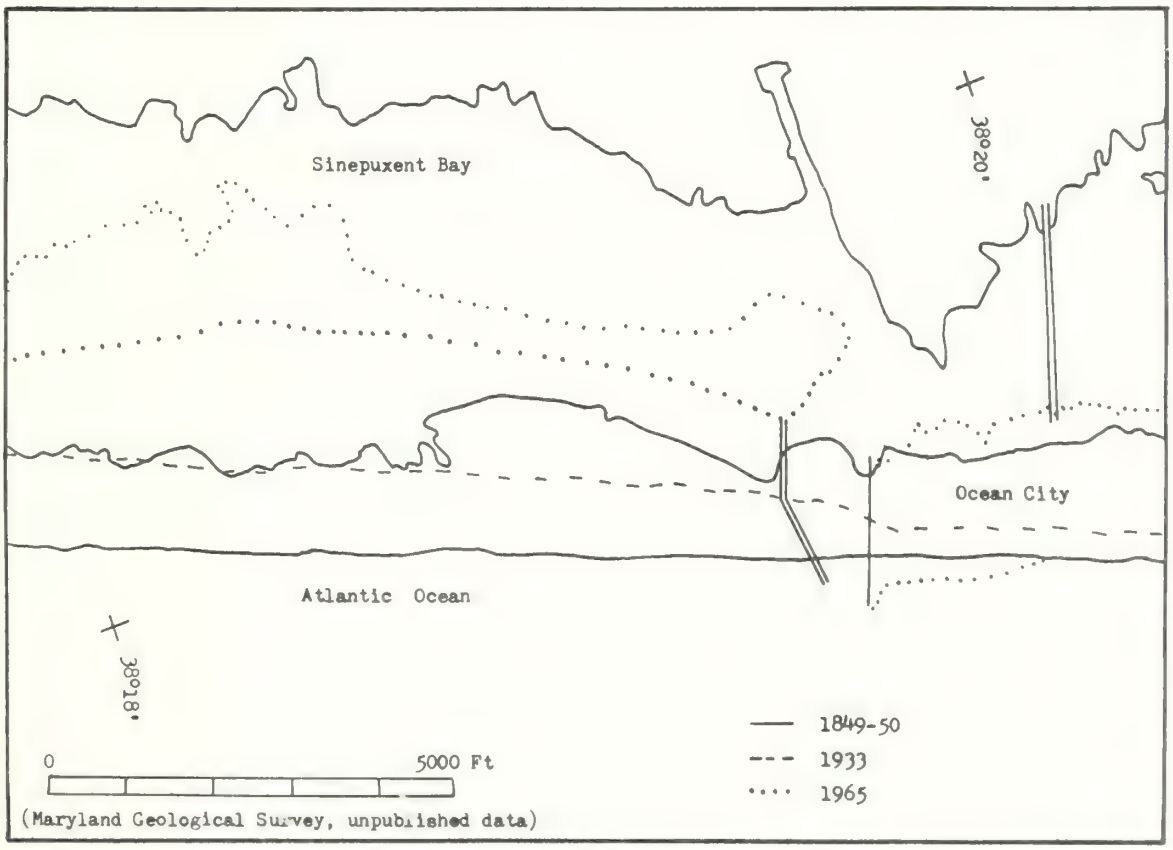

FIGURE 7.

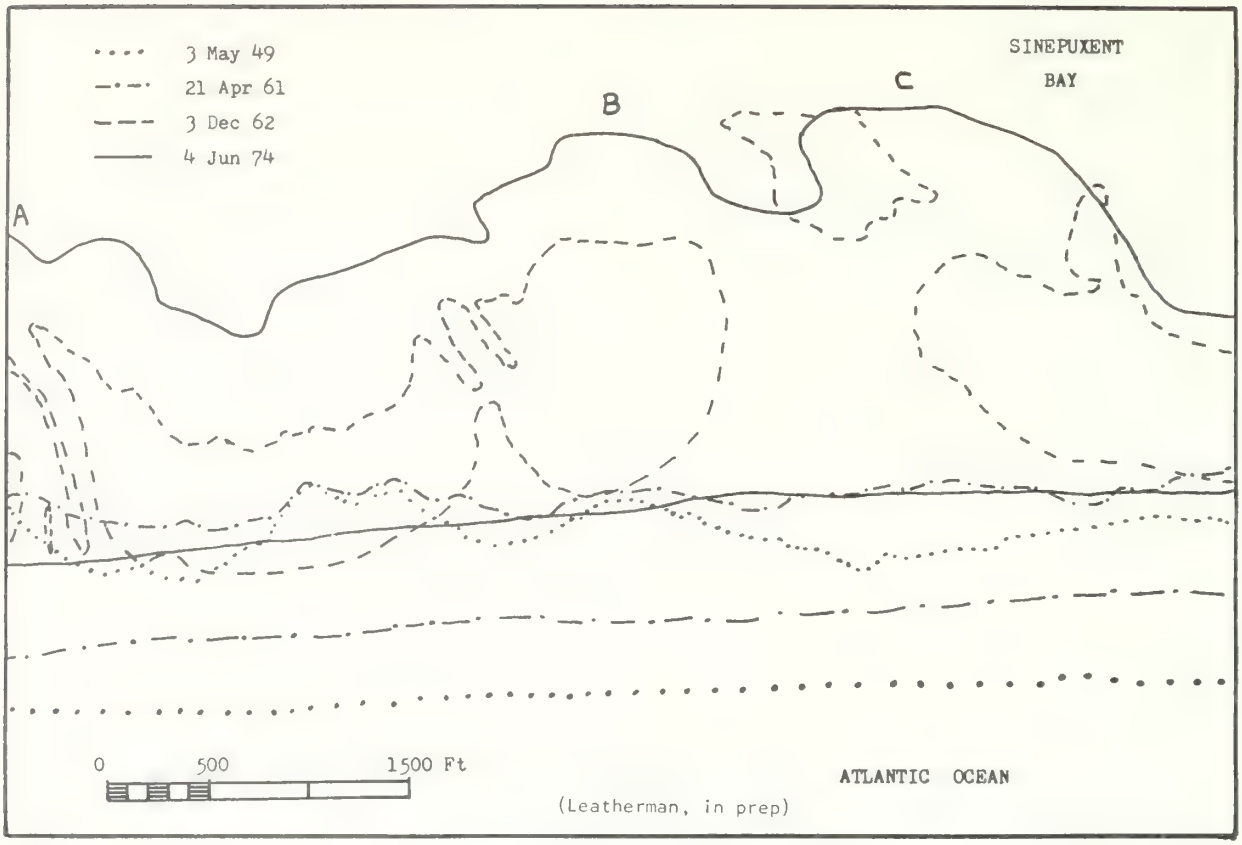

FIGURE 8.

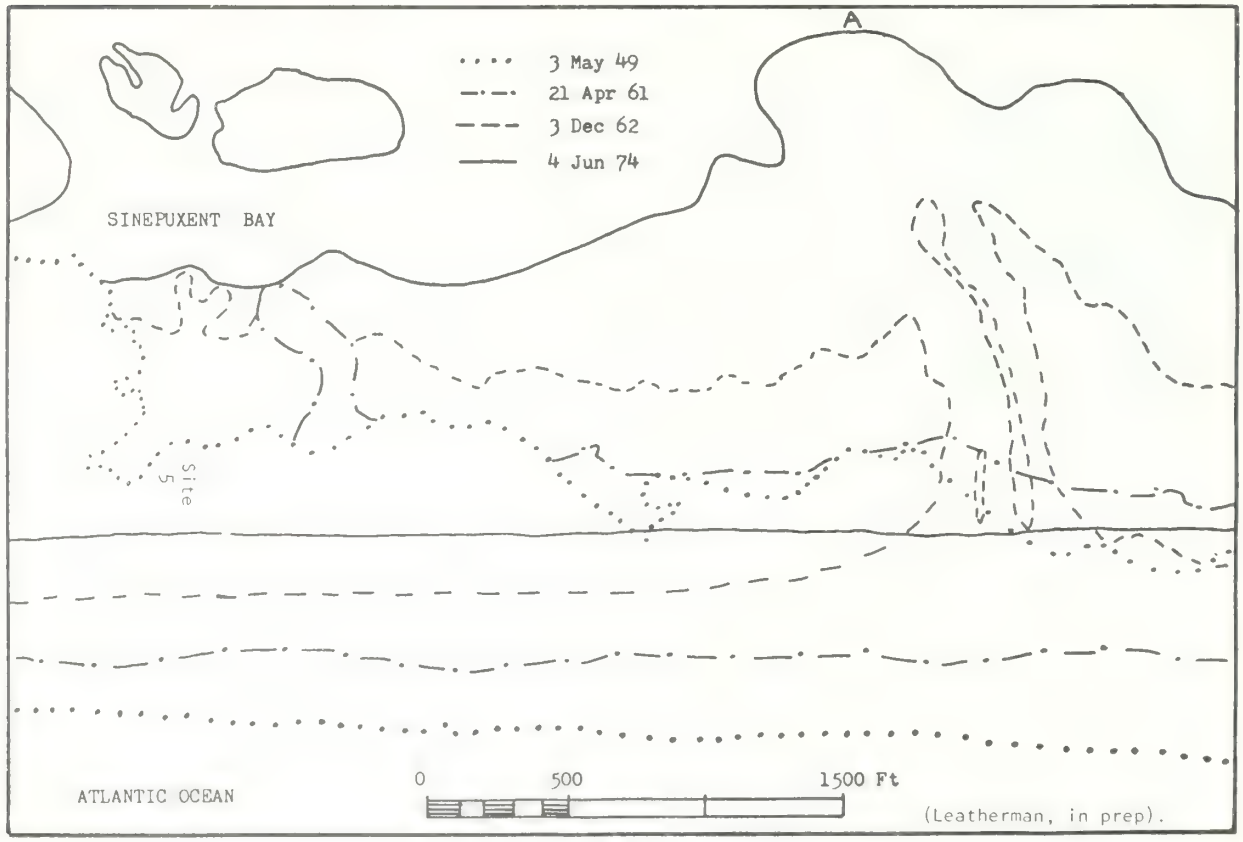

FIGURE 9.

The historical shoreline analysis demonstrated the dominance of inlet dynamics as compared to overwash processes for landward barrier migration. The geological significance of overwash is interpreted to be largely confined to bayshore "straightening" along most reaches, except where the shoreline has narrowed to a critical width. Inlet breaching and subsequent flood tidal delta formation is viewed as the only mechanism by which the island can exceed the 700 feet width limitation, consistent with an eroding shoreline.

MANAGEMENT IMPLICATIONS

The next task is to translate this basic research into management objectives. Much of this work is still in progress, and I will only raise several points for consideration. If overwash is not sedimentologically significant, then the practice of repairing barrier dunes after storms may have few adverse effects. Dune maintenance is viewed as more a cost-benefit than a geological problem.

For critical erosion areas, such as the northern end of Assateague island, it may not be possible or desirable to maintain a dune line. In some Seashores the continuity of the barrier dune is necessary for transportation reasons. Problems involve the developments that are encouraged by a false sense of security that is afforded by a dune. The National Park Service is now well aware of the risks associated with and costs involved in the protection of structures too close to the shoreline.

With incessant beach erosion, the barrier island will continue to narrow, regardless of the presence or absence of a dune. Overwash only becomes an effective transport mechanism when a critical width is reached. Inlet dynamics will be somewhat curtailed by a high barrier dune. It should be noted, however, that most inlets actually originate as outlets due to flowage of storm surge waters over the island to the ocean as the storm proceeds northward.

The maintenance of a dune will slow the beach erosion rate by acting as a source of sand to the beach during storm conditions and by offering protection to the backdune vegetation. The presence of vegetation is a key to the stability of a barrier. During a really major storm, such as a landfall hurricane, the barrier dune in a critical erosion area will be overtopped and flattened. Much of the sand derived from this area will serve as a source of material to the overwash surges. These large magnitude, low frequency events accomplish a significant amount of the geologic work. Other questions, regarding the functioning of a continuous barrier dune as a permeable seawall during storms, will not be explored at this time since this problem is still being studied at Nauset Spit (Cape Cod National Seashore).

Finally, it should be stated that each barrier beach, island or spit, must be evaluated individually. There is a marked geographic variation in the different physical and biological factors along the East and Gulf Coasts. Therefore, it is not possible to apply directly the results of a study in one Seashore to the problems in another. This type of basic data must be generated for each Park along the discontinuous barrier chain, since master plans cannot be based totally on armchair science.

LITERATURE CITED

GODFREY, P.J., 1970. Oceanic overwash and its ecological implications on the Outer Banks of North Carolina, Office of Natural Science Studies, National Park Service, Washington, D.C., 37 p.

LANGFELDER, J., D. STAFFORD, and M. AMEIN, 1968. A reconnaissance of coastal erosion in North Carolina: North Carolina State University, Department of Civil Engineering, 127 p.

LEATHERMAN, S.P., 1976a. Barrier island dynamics: overwash processes and eolian transport, Proceedings of the 15th International Coastal Engineering Conference, Honolulu, Hawaii, 17 p.

LEATHERMAN, S.P., 1976b. Barrier island migration: an assessment of the overwash process, Abstracts with Programs, Geological Society of America, Northeast-Southeast Sections, V. 8, p. 215.

LEATHERMAN, S.P., in preparation. Barrier island migration: an assessment of the overwash process (full paper).

MARYLAND GEOLOGICAL SURVEY, unpublished data, Historical shoreline changes.

STAFFORD, D., 1971. An aerial photographic technique for beach erosion surveys in North Carolina, U.S. Army Coastal Engineering Research Center, Tech. Memo. 36, 115 p.

TRAVIS, R.W., 1976. Interactions of plant communities and oceanic overwash on the manipulated barrier islands of Cape Hatteras National Seashore, North Carolina, Ph.D. dissertation, University of Massachusetts-Amherst, 134 p.

INTERACTIONS OF PLANT COMMUNITIES AND OCEANIC OVERWASH ON THE MANIPULATED BARRIER ISLANDS OF CAPE HATTERAS NATIONAL SEASHORE, NORTH CAROLINA

Richard W. Travis[1] and Paul J. Godfrey[2]

Cape Hatteras National Seashore is part of the Outer Banks of North Carolina. There are five factors which determine the natural vegetation patterns of sandy barrier islands such as these:

1. Tidal range and periodicity (Adams 1963)
2. Depth of the water table (Chapman 1964; Travis 1976)
3. Salt spray (Wells and Shunk 1938; Oosting and Billings 1942; Boyce 1954)
4. Blowing sand (Oosting and Billings 1942; Hosier 1973; vanderValk 1974; Travis 1976)
5. Oceanic overwash (Godfrey 1970; Godfrey and Godfrey 1971; Hosier 1973; Travis 1976).

In the past six years there has been much discussion about the nature of the primeval vegetation of the Outer Banks. Unfortunately, reliable descriptions of the vegetation did not appear until 1853 when maps showing the distribution of woods, marsh, and beach were made. The first thorough written descriptions were published in the early 1900's. (See Kearney 1900a&b; Coker 1900; Harshberger 1911; Bond 1908.) By the time these studies were made, the Outer Banks had been settled for over 200 years. Therefore, they did not necessarily reflect the true nature of the primeval vegetation.

There are two theories about the pre-settlement vegetation of the Outer Banks. One theory is that there was a sparse vegetation similar to that on present day Core Banks (Godfrey 1970; Dolan et al. 1973). The other proposes that the "natural" vegetation was considerably more dense than that now found on Core Banks (Bond 1908; Woodhouse 1974).

The main contention between supporters of these two theories is whether the vegetation described in the early 1900's and the present day vegetation of Core Banks are primarily the result of oceanic overwash, or of over grazing by domestic animals. Supporters of the Overwash model believe that grazing animals have not had a significant influence on the vegetation. They propose that Core Banks is a true reflection of the five factors listed above. Furthermore, they believe that overwash plays the dominant role in shaping both island physiography and vegetation. Supporters of the Grazing model propose that the vegetation of Core Banks is the result of the five factors listed above working on a vegetation that has been severely depleted because of over grazing by sheep, hogs, cattle, and horses.

This controversy is largely academic since it revolves around 200 years of poorly documented history. More practical points to argue are what has been the effect of the barrier dune systems on Cape Hatteras National Seashore? How will the vegetation there react to storm disturbances? What do these findings have to say about the management of the barrier islands?

Supporters of the Overwash model advance two points. They say barrier dunes have resulted in increased erosion of the beaches of Cape Hatteras. And, they believe the vegetation behind the dunes has decreased in its ability to recover from the effects of storms (Dolan et al. 1973).

The questions that we will consider then, are: What is the vegetation on and behind the barrier dunes of Cape Hatteras? How do storms breach the barrier dunes? To what extent is the vegetation able to recover from storm damage?

The plant communities of the dunes and barrier flats of Cape Hatteras are distinct from similar communities on barrier islands north and south of the Seashore. The dunes of Cape Hatteras are dominated by *Uniola paniculata* and *Ammophila breviligulata*. Accreting dunes usually have only one species of grass and no herbs. Dunes that are not accumulating new sand are also dominated by these two grasses, but herbs, vines, and other grasses grow with them.

North of Cape Hatteras *U. Paniculata* is not an important species and is rarely found north of Chesapeake Bay (Fernald 1950). South of Cape Hatteras *A. breviligulata* is a rare species and the dunes are dominated by *U. paniculata* (Radford et al. 1968).

At Cape Hatteras the barrier flats are characterized by communities of *Spartina patens*. These communities take two basic forms: a dry and a wet community. The dry community has *S. patens, A. breviligulata, Andropogon virginicus, Muhlenbergia capillaris,* and *Eragrostis pilosa* in various mixtures. Growing with these dominant grasses are the herbs and minor grasses found on the stable dunes. The wet community is an association of *S. patens, Andropogon virginicus, Juncus polycephalus, Scirpus americanus,* and *Fimbristylis spadecia*. There are also minor grasses, sedges, rushes, herbs, and shrubs, none of which are commonly found on the dry meadows or dunes. (Detailed descriptions of the vegetation can be found in Brown 1959; Burk 1962; Travis 1976.) The water table beneath the wet community is usually less than 50 cm below the surface and the area may flood during a heavy rain. The water table of the dry community is generally 50 to 150 cm below the surface and rarely floods.

The barrier flats of Virginia are dominated by *A. breviligulata*. *Spartina patens* is only a secondary member of the communities (Higgins et al. 1971). On Core Banks the vegetated barrier flats are dominated by *S. patens* and *Solidago sempervirens* on the drier sites, while *S. patens* with sedges dominate the wetter sites (Godfrey 1970). This wet community is similar to the wet community found on Cape Hatteras, but the dry community is more sparsely vegetated than its Hatteras counterpart.

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[2]National Park Service Cooperative Research Unit, University of Massachusetts, Amherst.

The communities of present day Cape Hatteras are also distinct from the communities found on Hatteras before construction of the barrier dunes. The pre-barrier dune communities were similar to those on present day Core Banks (compare Kearney 1900a to Godfrey 1970). *Ammophila breviligulata* was absent from the dunes and sedges were abundant in the interdune areas. Large areas that are now covered with barrier dune and barrier flat vegetation were barren sand flats. The main effect of the barrier dune and planted grasses has been the development of an extensive and dense meadow and dune vegetation.

Since the barrier dunes were built they have been kept in fairly good repair. When storms breached the dunes, new sand fence and grasses were set out. The plantings were periodically fertilized to ensure their survival. At present only about 15% (about 17 km) of the barrier dunes are overwashed or in danger of being overwashed by moderately sized storms. The process by which the barrier dune is breached begins with erosion of the dune's oceanward face. These are carried along the beach and out into the nearshore ocean by longshore and rip currents. This type of erosion continues until waves begin to overtop the dune. From then on, water runs down the back side of the dune eroding it from behind. A feature similar to a waterfall may form and gradually erode its way oceanward through what is left of the dune, much the way a waterfall erodes its way up stream in a river. In the final stages of gap development the miniature waterfall disappears and becomes the typical beach berm. A profile of the overwash gap would now show the beach gently sloping up to the berm, then, sloping down across the overwash deposit. The deposit may either taper off gradually or end abruptly depending on the topography of the site. The plant community lying beneath the overwash deposit is usually some type of *Spartina* community. Therefore, the response of *S. patens* to burial is of prime importance for proper management of these barrier islands.

It appears that the thickness of overwash deposits on Hatteras Island is greater than the thickness of deposits on Core and Shackleford Banks. Hosier (1973) found deposits on Shackleford Bank of no more than 12 cm from hurricane Doria in 1971, with a frontal storm creating deposits of no more than 4 cm depth. Godfrey and Godfrey (1973) reported some deposits as deep as 50 cm on Core Banks resulting from hurricane Ginger in 1971. They noted, however, that the general rate of deposition was considerably less, averaging only 8.4 cm of accumulated sand in ten years of overwashes along 39 km of beach (Godfrey and Godfrey 1973). On Hatteras Island we found deposits 96 cm deep resulting from two winter storms in 1973. Our observations indicate that depths of 30 cm or more can be expected the first time overwash occurs between two lines of barrier dunes or in an area of wet meadow vegetation. The reason for the thicker deposits on Hatteras Island is that two lines of barrier dunes or dense vegetation impound the overwash water and cause it to drop its sediment load close to the gap in the dune line. Where these features do not exist, the water spreads out and deposits its load over a greater area. After the initial thick deposit has been made, the depths of overwash on Hatteras Island are similar to those found on Core Banks.

Godfrey (1970) showed that *S. patens* communities on Core Banks were able to grow through the fairly shallow deposits common there. Artificial burials by Godfrey and Godfrey (1973) and Hosier (1973) showed *S. patens* growing in dry or wet meadows or in high salt marsh could grow through burial sand. They also showed that the rate of recovery decreased with increased depth of burial.

Our observations of natural and artificial burials at Cape Hatteras showed that there were four ways plants can colonize an overwash deposit:

1. Buried plants can grow through the overwash
2. Buried fragments can take root
3. Plants around the edge of the overwash can grow out onto the new sand
4. Seeds in the drift line can germinate.

Only two species, *S. patens* and *A. breviligulata*, were observed to utilize all four means of propagation. *Uniola paniculata* was not observed to take root from fragments. However, this is the normal means of artificial propagation, and it is likely that it happens in nature. *Panicum amarum* and *P. amarulum* were not observed as seedlings. Here too, though, it is likely that seedlings do occur. Therefore, at least two and more likely five species of grasses are capable of all four means of colonizing overwash deposits

In addition to these five species eighteen other grasses, herbs, and vines were found growing on overwash deposits during the first growing season after deposition. This means that at least twenty-three species of meadow plants are able to participate in the colonization of an overwash deposit.

What, then, is the most likely scenario for the response of the vegetation of Cape Hatteras National Seashore to oceanic overwash?

Most of the gaps formed in the barrier dunes will not be revegetated by natural means. When a gap is formed the dune plants are carried away by the waves and end up in drift lines perhaps kilometers away from their place of origin. Therefore, there are no plants left in the gap to grow through the overwash. Drift lines, which contain viable seeds and fragments of plants, are usually not left in overwash gaps, so these two sources of plants are also of little significance here. The only sources of new plants to colonize an overwash gap are the dunes on either side of the gap. This may or may not be an effective source of plants. If the gap is wide or the sides of the dunes steep, it is difficult for *U. paniculata* or *A. breviligulata* to grow out into the gap.

Vegetation behind the barrier dune should show better recovery from overwash. There will, however, be changes. Any species not adapted to survive burial will disappear from the site. These species, notably shrubs, will not return as long as there are periodic overwashes.

Since vegetation is related to the depth of the water table, changes may be caused by the raising of the soil surface. If 30 cm of sand are deposited on a wet meadow, the recolonizing species will be more characteristic of the dry meadow than of the wet. The effects of elevation rise would be most pronounced on the wettest sites. These sites contain the most species unable to survive burial or drier conditions, and should record the greatest rise in elevation.

During the early stages of gap and deposit formation the only plants to suffer from erosion are those in the immediate vicinity of the gap. However, as more overwashes occur the pattern of erosion and deposition changes. Fisher et al. (1974) described the movement of sand on an old

overwash deposit during a storm. As the storm increased in intensity sand on the surface of the old deposit was eroded away and laid down on previously unburied vegetation. As the storm intensity slackened new sand was deposited on the old overwash surface. This pattern of erosion and deposition means that a storm which raised the elevation of an old overwash deposit by 5 cm may actually have involved the erosion of 10 cm and subsequent deposition of 15 cm of sand, resulting in the net elevation rise of 5 cm.

It seems likely that during the erosion phase of a storm plants growing on the old deposit could be washed away leaving a barren area which is an unlikely candidate for natural revegetation. This is the probable reason for the broad beaches on Core Banks.

What conclusions and management guidelines can be derived from this investigation?

1. The construction of the barrier dune and planting of grasses at Cape Hatteras National Seashore have resulted in a vegetation that is unique both in its species composition and in the density and area covered by vegetation.

2. This vegetation is fully capable of recovering from overwash burial as long as succession is not allowed to proceed beyond the grass stage.

3. To predict the ability of vegetation to recover from a given overwash one not only needs to know the type of vegetation buried and how deeply it was buried, but, one also needs to know the pattern of erosion and deposition during the storm.

It appears that the vegetation of the dunes and barrier flats of Cape Hatteras is equally capable of recovering from overwash as the vegetation of Core Banks. Indeed, Cape Hatteras may be better suited for recovery since it has denser vegetation to start with.

Both sides in the argument over whether the barrier dune is good or bad for the vegetation seem to believe barrier island vegetation is unusually fragile. One side argues that because barrier islands are subject to such severe stresses they are not meant to support an extensive vegetation. The sparse dunes and meadows are vital to preserving the overwash process and should not be disturbed. The other side argues that the islands are able to support a fairly extensive vegetation, but this vegetation was disturbed by over grazing. Consequently, barrier dunes were needed to restore the vegetation before storms did it more damage.

Our research leads us to believe that the vegetation of the Outer Banks is a lot less delicate than either side believes. We also conclude that the dense vegetation of the barrier dune system is not harmful as long as the vegetation is dominated by species adapted to live with overwash. It is evident, though, that barrier dunes are not suited for every kilometer of the Outer Banks. Some sites by virtue of their exposure and aspect are more subject to overwash than others. These sites should have a sparse vegetation similar to parts of Core Banks. Barrier dunes on these sites seem best suited for causing people to get up in arms, either because they see tax dollars going out with the ebb tide, or because they think more tax dollars will keep the flood tide from coming in.

LITERATURE CITED

ADAMS, D. A. 1963. Factors influencing vascular plant zonation in North Carolina salt marshes. Ecology. 44:445-456.

BOND, J. F. 1908. Report on an examination of the sand banks along the North Carolina coast. In Biennial Report of the State Geologist. J. H. Pratt state geologist. Raleigh. 60pp.

BOYCE, S. G. 1954. The salt spray community. Ecol. Mono. 24:29-67.

BROWN, C. A. 1959. Vegetation of the Outer Banks of North Carolina. Baton Rouge: Louisiana State Univ. Press. 179pp.

BURK, J. C. 1962. The North Carolina Outer Banks: a floristic interpretation. J. Elisha Mitchel Sci. Soc. 78: 21-28.

CHAPMAN, V. J. 1964. Coastal Vegetation. New York: The MacMillan Co. 245pp.

COKER, W. C. 1900. Notes on the flora of the banks and sounds at Beaufort, North Carolina. Bot. Gaz. 30:405-410.

DOLAN, R., P. J. GODFREY, and W. E. ODUM. 1973. Man's impact on the barrier islands of North Carolina. Am. Scientist. 61:152-162.

FERNALD, M. L. 1950. Gray's Manual of Botany, 8th Ed. New York: American Book Co. 1632pp.

FISHER, J. S., S. P. LETHERMAN, and F. C. PERRY. 1974. Overwash processes on Assateague Island. In Proceedings of the 14th Coastal Engineering Conference, Copenhagen, Denmark, June 1974. Am. Soc. of Civil Eng. chapt. 70. pp. 1194-1212.

GODFREY, P. J. 1970. Oceanic overwash and its ecological implications on the Outer Banks of North Carolina. Office of Natural Science Studies National Park Service, Washington, D. C. 33pp.

GODFREY, P. J. and M. M. GODFREY. 1971. Barrier island ecology of Cape Lookout National Seashore and vicinity, North Carolina. AAAS Symposium on Research in the National Parks. 66pp.

GODFREY, P. J. and M. M. GODFREY. 1973. Comparison of ecological and geomorphic interactions between altered and unaltered barrier island systems in North Carolina. In Coastal Geomorphology. D. R. Coates, ed. St. Univ. of N. Y. pp. 239-358.

HIGGINS, E. A. T., R. D. RAPPLEYE, and R. G. BROWN. 1971. The flora and ecology of Assateague Island. A172. Univ. of Maryland Agr. Exp. Stat. College Park Md. 70pp.

HOSIER, P. E. 1973. The effects of oceanic overwash on the vegetation of Core and Shackleford Banks, North Carolina. Ph.D. dissertation Dept. of Botany. Duke Univ. Durham, N. C. 230pp.

KEARNEY, T. H. 1900a. The plant covering of Ocracoke Island: a study of the ecology of North Carolina strand vegetation. U. S. Nat. Herbarium Contribution. 5:261-319.

_____. 1900b. Report on the botanical survey of the Dismal Swamp region. U. S. Nat. Herbarium Contribution. 5:321-550.

OOSTING, H. J. and W. D. BILLINGS. 1942. Factors affecting vegetational zonation on coastal dunes. Ecol. 23:131-142.

RADFORD, A. E., H. E. AHLES, and C. R. BELL. 1968. Manual of the Vascular Flora of the Carolinas. Chapel Hill, N. C. Univ. of N. C. Press. 1183pp.

TRAVIS, R. W. 1976. Interactions of plant communities and oceanic overwash on the manipulated barrier islands of Cape Hatteras National Seashore, North Carolina. Ph.D. dissertation. Dept. of Botany. Univ. of Massachusetts. Amherst, Ma. 134pp.

VAN DER VALK, A. G. 1974. Environmental factors controlling the distribution of forbs on coastal foredunes in Cape Hatteras National Seashore. Can. J. Bot. 52:1057-1074.

WELLS, B. W. and I. V. SHUNK. 1938. Salt spray: an important factor in coastal ecology. Bull. Tor. Bot. Club. 65:485-488.

WOODHOUSE, W. W. 1974. Letter to J. Dunning, Superintendent Cape Hatteras National Seashore January 10th.

BARRIER ISLAND STUDIES, MISSISSIPPI-ALABAMA GULF COAST[1]

Ervin G. Otvos, Jr.[2]

INTRODUCTION

The Mississippi-Alabama chain of barrier islands and shoals stretches for an approximate distance of 140 km between the southwestern Mississippi mainland and Mobile Bay entrance. Some of the islands are farther offshore (maximum 20 km) than any other ones of the Gulf-Atlantic coasts, save the Outer Banks of North Carolina. Island lengths range between 3-24 km and widths vary between 200 m and 2 km. While the total of the six island areas (c. 48.4 sq km) almost equals that of the Bermudas, a small permanent population (c. 400-500) exists only on the largest one, Dauphin Island. Due to the dominant southeasterly wave approach direction, sediment movement on and off the beaches is westward. The large ebb-tidal delta off Mobile Bay transmits sands from the Alabama mainland (Mobile Point Peninsula) to eastern Dauphin Island. Similar, but smaller ebb-tidal deltas perform identical functions south of the passes between the islands, east of West Ship Island. Differences between Sound and Gulf coastal energies are reflected by the greater widths of the Gulf beaches. Interestingly, the median grain sizes-wave energies show inverse relationships, except on strongly eroding Cat Island and on East Ship Island (Otvos 1975b).

Until recently, the subsurface makeup and evolutionary history of the islands have been a matter of conjecture. McGee, probably the earliest exponent of the island formation theory through mainland engulfment, speculated (1890, p. 440-443) that the islands were left behind by the Holocene transgression. Results of rotary core-drilling by the Geology Division of the Gulf Coast Research Laboratory since 1973 shed new light on the problem on the evolution of the Mississippi Sound and certain islands. Detailed biostratigraphic analysis of the Holocene sequence through the study of foraminifers allowed facies interpretations and at least a partial reconstruction of the Holocene marine events.

The most detailed study has been carried out only of Dauphin Island but several coreholes have also been drilled on the other islands and off Cat Island. Safe conclusions with regard to island genesis have been reached only on Dauphin Island. More work is required on the other islands before the present working theories on island evolution may be confirmed or refuted.

GEOLOGICAL FRAMEWORK OF THE NEARSHORE ZONE

Miocene. The oldest units encountered by the island drillings belong to the Miocene Pascagoula Formation. It consists of nearshore, inshore and alluvial-fluvial deposits. Typically, stiff- to very stiff, dark and moderately greenish gray muds and clays represent it. Poorly sorted, slightly granular, medium sands, sandy corase silt, moderately sorted medium and fine sands alternate with the clay and mud layers. Occasionally, the muds and clays include nearshore foraminifers, identical to those found in Quaternary deposits. When a sequence of non-descript, often sterile sands is present between the Pascagoula muds, and sandy younger units, the upper surface of the Miocene unit can not be safely determined. The Miocene surface slopes southwestward and is dissected by gullies and small valleys.

Pliocene - Pleistocene units. Fossil-free, detrital beds of unknown age(s) were occasionally found between the Miocene units and the Late Pleistocene Biloxi Formation. These sandy-muddy deposits, often with plant debris were likely deposited in alluvial-fluvial environment.

Late Pleistocene Units.

Biloxi Formation (Sangamon Interglacial)

Gray, semiconsolidated, maximum 12 m thick muddy sands and sandy muds with a rich microfauna make up this formation (Otvos 1975a). Under the coastal Gulfport Formation it represents the transgressive phase of the Sangamon, but offshore, in all liklihood it also includes younger beds that are time-correlative with the Gulfport. A whole range of nearshore facies are represented. Under the present barrier islands, the foraminifer spectra most often reflect open, inner shelf conditions. A good example for this was found in drillhole #1, East Ship Island, 55'-55'6" (in percentages):

Elphidium galvestonense	19.6
Hanzawaia strattoni	16.5
Buliminella elegantissima	7.8
Nonion depressulum matagordanum	7.8
Cribroelphidium poeyanum	5.4
Ammonia beccarii tepida	5.2
Elphidium incertum mexicanum	4.1
Nonionella opima	3.7
Quinqueloculina lamarckiana	3.7
Quinqueloculina fragments	3.4
Nonionella atlantica	2.8
Quinqueloculina seminulum	2.6
Ammonia beccarii parkinsoniana	2.5
Bigenerina irregularis	1.6
Buccella hannai	1.5
Nonion affinis	1.2
Rosalina columbiensis	1.1
Guttulina australis	0.8
Elphidium translucens	0.7
Brizalina lowmani	0.5
Guttulina hirsuta	0.5
Quinqueloculina compta	0.5
Quinqueloculina polygona	0.5
Sagrina pulchella primitiva	0.5
Bulminella cf. *B. bassendorfensis*	0.4
Elphidium delicatulum	0.4
Fursenkoina compressa	0.4
Reussella atlantica	0.4
Elphidium advenum	0.3
Elphidium sp.	0.3
Fursenkoina pontoni	0.3
Quinqueloculina poeyana	0.3
Quinqueloculina tenagos	0.3
Spiroloculina soldanii	0.3
Triloculina brevidentata	0.3
Ammobaculites exiguus	0.2

[1]The National Park Service provided drilling rig transportation to several of the investigated islands. The assistance of Superintendent Noel J. Pachta is greatly appreciated in this respect. Results of foraminifer analyses were provided by W. D. Bock. The cited radiocarbon age determinations were performed at the Geochronology Laboratory, University of Georgia.

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Ammotium salsum	0.1
Asterigerina carinata	0.1
Brizalina striatula	0.1
Cancris oblonga	0.1
Cassidulina subglobosa	0.1
Cibicides floridanus	0.1
Cibicides lobatulus	0.1
Epistominella vitrea	0.1
Fissurina sp.	0.1
Globigerinoides ruber	0.1
Guttulina laevis	0.1
Quinqueloculina sabulosa	0.1
Triloculina tirgonula	0.1
Triloculina trigonula multistriata	0.1
Uvigerina peregrina	0.1

Total number of specimens: 757

Gulfport Formation (Sangamon Interglacial)

Sand deposit, accumulated in beach-dune ridges along the Mississippi-Alabama mainland shores during the last interglacial (Otvos 1973). Its greatest thickness is 8 m and it contains no fossils. Humate impregnations in its lower levels are common and they impart an almost black color to the sediment. In addition to the three coastal segments where the Gulfport ridges are present on the Mississippi coast, the Formation and its correlative units are known from most of the northern Gulf coast, including the Alabama coastal area east of Mobile Bay.

Prairie Formation (Sangamon and Wisconsin)

Sandy and silty, alluvial-fluvial deposits with occasional plant fragment compose this unit. It formed landward of the Gulfport barrier ridges during the Sangamon high sea level and with the recession of the sea was deposited also seaward of the ridges. Prairie sediment accumulation locally may have lasted well into the Wisconsin. In offshore areas, where the possibly Prairie deposits do not overlie the Biloxi Formation, distinction is impossible between the Prairie and earlier alluvial-fluvial sediments.

Holocene

The Holocene transgression by about 6,500-6,000 years B.P. did reach the area of the barrier islands (Otvos in press). Island formation is believed to have started some time after the sea reoccupied this area and probably somewhat before or at the time the present sea level was reached at 4,000-3,500 yrs. B.P. Semi- and unconsolidated, and loose muddy, sandy-muddy deposits dominate bottoms of the Mississippi Sound and its bays. Sands dominate the barrier island belt. The greatest thicknesses (15-21 m) have been found under Ship and Horn Islands.

Distinction between Holocene and Pre-Holocene Units. The separation of the Holocene sediments from earlier units, with the exception of eastern Dauphin Island, was rarely without problems. With two exceptions, the pre-Holocene land surface under the islands is not characterized by oxidized, yellowish-brown sediments, as generally is assumed. This fact may be due to subaqueous reduction processes. Where muddy-sandy, probably alluvial deposits, that contain plant fragments and no marine fauna elements underlie the Holocene, the boundary between these deposits and the fossiliferous Holocene sediments is accepted as the Pleistocene surface. On one occasion, such plant fragments provided a 40,000 yrs. B.P. ("dead") date north of East Ship Island. The consistency of the sediments alone does not always yield a "foolproof" distinction between Holocene and pre-Holocene units. The fossiliferous medium silts, muds and muddy fine sands, underlying the barrier sands of Horn Island, for instance, frequently yielded penetrometer values of 0.5-1.25 ton/sq ft, in contrast to the mostly unconsolidated, or even loose Holocene sediments. A 5-7 ft thick oxidized silt and sand unit, clearly reflecting the earlier Pleistocene land surface, underlies these Holocene muddy units in corehole #10.

The distinction is especially difficult where the Holocene fossiliferous sediments directly overlie earlier units with a very similar microfauna (Biloxi Formation). When foraminifers, in contrast with the fresh look of the Holocene ones, have a bleached, weathered appearance in the older units, a stratigraphic separation is feasible.

Facies.

Micropaleontological, primarily foraminiferal analyses provide the best tool in interpreting the various biofacies, which primarily reflect salinity conditions. Such studies agree with earlier bottom facies studies (Phleger 1954, 1960; Walton 1960; Upshaw and others, 1966) in the same general area, and established a number of biofacies for both the present sediment bottoms and the vertical sedimentary sequences, found in core-drilling, as well. The facies ranged between two extremes; the inshore-close nearshore, highly brackish one, and the most saline, open marine inner shelf facies.

Highly brackish facies (Biloxi-Biloxi Back Bay, St. Louis Bay, northern and western Mississippi Sound). In areas which are exposed to fresh water runoff for the longest duration agglutinate forms (*Ammotium salsum, Ammobaculites exiguus, Reophax nana, Textularia earlandi, Miliammina fusca)* dominate (60-100% of total foraminiferal population), with a preponderance of *Ammotium salsum* (40-86% of total). Two varieties of *Ammonia beccarii* (*tepida* and *parkinsoniana)* are preeminent among the calcareous forms, occasionally representing 23% of the total population. *Elphidium galvestonense, E. incertum mexicanum, E. gunteri, Cribroelphidium poeyanum,* and several other calcaerous species were present in very minor amounts. Bottom salinities in the Mississippi Sound show wide year-round variations (Christmas and Eleuterius, 1973 p. 99-104): between 2-34 parts per thousand. Even in the highly brackish western parts, with the preponderance of agglutinate species (Upshaw 1966, and others, Plate 4), the salinities during 1973-75 ranged between 2-30, with values of 10-24 ppt in the vicinity of Cat Island.

As salinity gradually increases, the agglutinate forms decline and *Ammonia beccarii* becomes predominant (40-80%). *Elphidium galvestonense, E. gunteri, E. incertum mexicanum,* and *Nonion depressulum matagordanum* may reach percentages of 4-9. The number of other calcareous species present also increases. Although *Ammonia beccarii* and other calcareous species have been found sporadically in significant amounts even in an oligo-mesohaline setting in highly brackish Lake Pontchartrain (Otvos in prep.), the stratigraphic relationship of the biofacies and the proportion of the other calcareous species in the Gulfport Harbor-West Ship Island line of drillings, clearly indicate the slightly less brackish character of this biofacies.

With further salinity increase, the proportion of agglutinates vanes faster than the simultaneous decrease in the *Ammonia beccarii* population. *Bulimina elegantissima, Nonion depressulum matagordanum* and *Nonionella opima* achieve significant percentages, and *Hanzawaia strattoni, Elphidium galvestonense, E. incertum mexicanum* and *Cribroelphidium poeyanum* also grow in importance.

Shelf conditions. Open marine conditions exist along the edge of the Mississippi Sound and in the passes between the islands, exposed to the influx of more saline waters. The foraminifer faunas greatly resemble the composition of high-salinity Biloxi Formation facies, mentioned before. Instead of 8-12 species, present in the "highly brackish" facies, the number of species reached 25-45. More species were found in muds than in the sands, possibly partly because of the winnowing effect in the later lithofacies. The most important species showed the following percentage ranges: *Elphidium galvestonense* (8-29%), *Hanzawaia strattoni* (9-54; occasionally due to secondary sorting, 72%), *Elphidium incertum mexicanum* (10-16.5), *Cribroelphidium poeyanum* (5-18%), *Bulimina elegantissima* (10-30%), *Nonion depressulum matagordanum* (3-41%), *Ammonia beccarii* (10-19). Occasionally, *Rosalina columbiensis* and *Quinqueloculina lamarckiana* (maximum 11%, each), *Nonionella opima* (8-26.5%) and *Remaneica* sp. (maximum 24-63%) also appear in very significant quantities.

Vertical Facies Relationships in the Holocene Sequence

A line of drillholes between Gulfport Harbor and West Ship Island yielded information showing that recent deposits, rich in agglutinated foraminiferal species, in the northern and central Mississippi Sound areas are underlain by earlier Holocene sediments with less brackish biota (dominated by *Ammonia beccarii* varieties and other calcareous forms; diminished percentages of agglutinates). Closer to West Ship Island, more exposed to marine influence, the biotas in the bottom deposits were also of more saline nature, but similar to the northern locations, graded downward into even less brackish units. From a core material offshore (east and north) Cat Island, as well as in a line of drillholes between Pascagoula and Petit Bois Island similar, preliminary data, inidcate that the upward increase of the brackishness of the Holocene facies beneath the Sound is not restricted to a single area. It seems not only that the present brackish, barred conditions of most of the Sound developed (probably with the emergence of barrier islands) toward the end of the Holocene, but also that prior to that period, open marine salinity conditions did not prevail everywhere in the present Sound area. This was not necessarily due to a barring effect by barrier islands during the earlier Holocene times, but to the considerable runoff from coastal rivers. No evidence exists for any earlier barrier island chain, north of the present one, during these times. However, a line of shoals which developed gradually along the Sound's southern margin prior to the emergence of the barrier islands might have enhanced the brackish conditions by its barring effect. Present-day inter-island shoals have the same effect on Sound salinities.

STUDY OF INDIVIDUAL ISLANDS

(1) *Dauphin Island.* Drilling of six coreholes on the easternmost and largest (area: c. 15.2 sq km) of the islands provided detailed information on the subsurface stratigraphy (Fig. 1). The island resembles the shape of a long-stemmed pipe. The eastern, broad island segment ("bowl") is 5.2 km long and maximum 2 km wide. On its southern shores, opposite the Mobile Bay ebb-tidal delta, large precipitation dunes reach elevations of 14 m. While Mobile Point Peninsula, on the opposite shore, extends well into the Bay and is still growing, the possibility that it reached the Island at one time during the Holocene, can safely be ruled out. The natural depth of the pass in front of the tip of the Peninsula is 11-16 m, reflecting the scouring action of powerful tidal currents. Prior to the Holocene transgression, the channel was probably occupied by the ancestor of the present Mobile and Tensaw Rivers. Similar passes between the islands and the need for direct tidal exchange of sound, bay and Gulf waters also obviate the possibility that a single continuous barrier island existed west of Dauphin

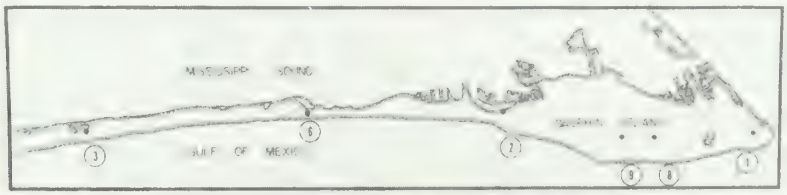

FIGURE 1. Barrier islands and barrier shoals of the Mississippi-Alabama coast. Approximate maximum extent of active St. Bernard subdelta, during third millenium B.P. based on present morphology and bottom sediment heavy mineral data. Dominant drift direction along north and south island beaches: westward.

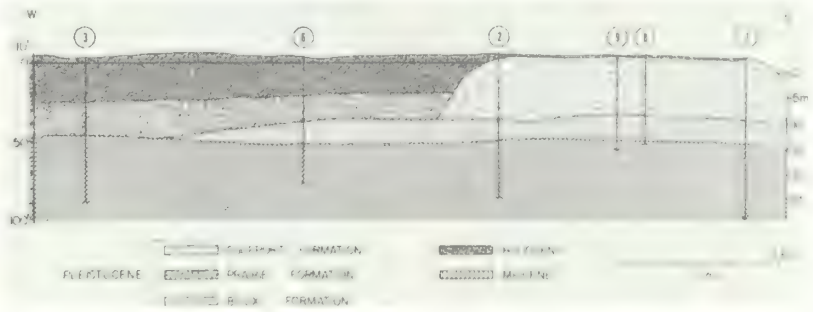

FIGURE 2. East-west cross section through Dauphin Island, Alabama.

Island in prehistoric times. These facts frustrate any theory which, similar to certain assumptions on the history of Mid Atlantic barrier islands, would propose that the Mississippi-Alabama barrier islands evolved through the storm segmentation of an original, long spit which grew westward from the Alabama mainland.

The western Dauphin Island segment ("stem") is a very narrow, long spit. Due to periodic hurricane destruction, its length fluctuated between 0-24 km (U.S. Army Engineer Div. 1971, p. 312) during the past half century. Marshes and low dunes cover its central areas. In the 1850's, a separate island was located here which later rejoined the rest of Dauphin Island. Certain 18th century maps show Dauphin continuous with Petit Bois Island. Whether Petit Bois Pass did not exist at all between these islands, can not be settled on the basis of these maps alone. In contrast to the more protected eastern island area, inhabited throughout historical times, resort development on the low, open western spit has been a recent and seemingly precarious development.

These two island segments also have a contrasting geological history. In the east, drillholes 1, 2, 8 and 9 encountered oxidized, yellowish brown and orange colored silty sands that overlie humate-impregnated sands under a thin veneer of Holocene eolian deposits (Fig. 2). A scarp at Fishing Pier beach (south shore) and trenches in the interior exposed the same sands. The fine- and medium, limonitized and humate-impregnated sands were poorly, medium well and well-sorted. Infiltration of soil matter, limonitized weathering products and humate influenced sorting. The limonitized and humate impregnated sands are believed to be equivalents of the Gulfport Formation barrier sands of the mainland. Humate precipitation and impregnation occurred from downward percolating surface waters with humic acids (Swanson and Palacas 1965), during the retreat of the Sangamon sea. In the 0.9-1.8 m depth interval of drillhole #8, the organic carbon content of the humate was 0.45%. The sample yielded a 7700±820 yrs. B.P. radiocarbon date (UGa-1266) after 523 g of sand were processed. This date must be due to more recent contamination of the original humate which precipitated when encountering higher pH conditions, as the result of sea water influence. Similar Gulfport Formation humates on the Mississippi Coast (Otvos 1973, 1976) yielded "dead" dates (over 36-40 thousand years B.P.). 7700 yrs. ago the sea level stood approximately 22.5 m below the present (Nelson and Bray 1970, p. 66) and sea waters could not have influenced solutions in the sands at present sea level elevations. The orange-yellow limonitized sands, similarly must have acquired their color during an extended Late Pleistocene-early Holocene subaerial exposure. Microfossils, as in known Gulfport deposits, are completely missing from the partly oxidized and humate-impregnated sands; intrastratal leaching is the probable reason.

A thin unit of Biloxi deposits underlies these sands, in term underlain by Miocene muds, as well as fine and medium sands. Radiocarbon-dated wood fragments from -12 m in coreholes #1 and #2, from below the Gulfport-equivalent sands, yielded dates of 23,500±3825 and 25,840±1330 yrs. B.P., respectively (UGa-557 and UGa-554). The fragments came from a unit, interpreted as part of the Biloxi Formation. Therefore, these dates have been equally "falsified" by more recent contamination. The Biloxi is partially missing beneath the western island segment and the Prairie Formation directly overlies the Miocene. Fossiliferous medium sands and interbedded mud and muddy fine sand layers represent the Holocene here. The transgressive Holocene unit in drillhole #3 includes an agglutinate foraminifer-rich clayey fine sandy unit. Medium shoal sands over it revealed an open shelf edge fauna (*Hanzawaia stratoni:* 34.8%, *Elphidium galvestonense:* 19.1%, and *Ammonia beccarii:* 11.3%). The composition of the same unit in drillhole #6 reflected more brackish conditions (*Ammonia beccarii:* 46.9%, *Elphidium gunteri:* 19.6%, *Ammotium salsum:* 10.6%). Drillhole #6 was closer to the sheltering easter part of the island, than was drillhole #3. The difference between the faunas probably reflected this influence which created somewhat barred, more brackish conditions behind the stable eastern island segment.

Islands of the National Seashore.

As of yet, only preliminary drilling results are available from the four islands. Similarly to Dauphin, East Ship and Petit Bois Islands consist of a broader "core" area and a narrow, low-lying spit-like appendage. The fact that in our drilling we encountered only Holocene sand and silty sand under the broader island segments, and sandy muds were found only under the shoal platform sands of the narrow segments, may indicate that the broader areas prior to the transgression also represented topographic highs. This way, shoal conditions could have been created above them in the early stages of the transgression. Between 1848-1973 Petit Bois gained 4.3 km on its western end and lost 11 km on the east. Its present area after (Waller and Malbrough 1976) is approximately 5.7 sq km. As in the case of Ship Island, in the course of the westerly island migration, small island segments separated during erosion from the eastern island areas, survived as islets for shorter periods of time. Even the southern shores of the broad island segments suffered extensive retreat: maximum 350 m on Petit Bois and 450 m on East Ship Island, between the 1850's and 1973 (Waller and Malbrough 1976). Three times between 1947-1969 Ship Island (total area in 1973: 3.9 sq km, after Waller and Malbrough 1976) was cut in two by hurricanes; the last cut was so extensive that it might stay permanent. Due to the changing erosional-accretional pattern, erosion also occurred on the northwestern shores of West Ship and Horn Islands, areas accreted only relatively recently. Eroding marsh in the lower beach zone and the Sound's encroachment on Fort Massachusetts (Henry 1976) are examples of this process.

Preliminary drilling on Horn Island revealed the presence of an approximatley 6 m thick, well consolidated Holocene muddy sandy, mud, silt, sandy mud unit under the shoal platform sands. As earlier mentioned, frequent 0.5-1.25 tons/sq ft pentrometer values indicated unusually firm consistency, very unusual when compared with the commonly loose or poorly consolidated similar Holocene deposits. The greater thicknesses (maximum c. 21 m) of the Holocene sequence under Ship and Horn Islands may reflect the presence of pre-Holocene topograpic lows in the subsurface and/or the proximity of the subsiding zone of the Mississippi Delta region.

Cat Island.

The unusual, reclining mushroom- or umbrella shape was formed by the combination of two island segments. The east-west trending segment, about 9 km long, is composed of three or four generations of beach-dune ridges which prograded in a southerly direction (Fig. 3), while the NNE-SSW segment (about 6 km long, at present) accumulated from the erosion of the other segment and partially overlaps it. In the absence of active dune fields on the east-west segment and due to slow subsidence, individual accretionary ridges have

been preserved far better than on any other island. The dense forest-shrub cover also plays a role in this. Marshes and ponds occupy the swales between the ridges and along the north shore intrusion of the Mississippi Sound waters into these lows create elongated, narrow embayments and islets. The separation of east-west trending Middle Spit, presently covered by marshland, was probably due to this process.

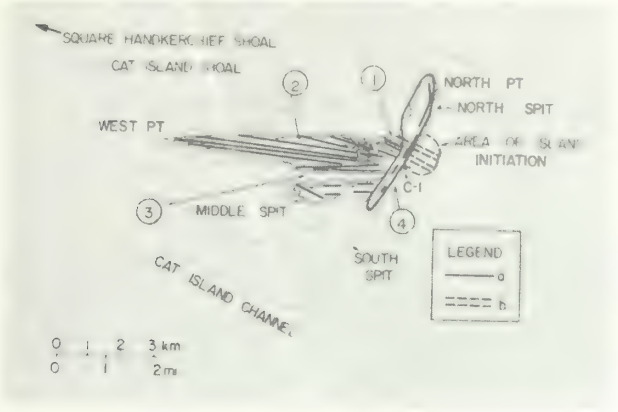

FIGURE 3. Cat Island. Three generations of accretion ridges discernible. Area "4" surrounded by thick line, represents the most recent island segment, an area of mostly active dunes and few trees. At present only a fraction of the original South Spit exists. Legend: (a) surface ridge generations; (b) projected original pre-erosional ridge positions in assumed area of island initiation.

The north-south-trending island segment is occupied by active dunes which spill over the eastern margin of the forested areas. Active shore retreat between 1848-1973 amounted to 250 m in the central section and is well documented by standing and eroding tree stumps in the surf zone. Periodic storms were responsible for the erosion of South Spit which at times extended almost 3 km further south (Waller and Malbrough 1976).

Considering the fast recession of the eastern shores, it is safe to assume that the original island nucleus was located northeast of drillhole C-1 (Figure 3), at considerable distance off the present eastern island shores. Shoal sands here overlie Holocene muddy sands, suggesting that Cat Island might have also started as a shoal platform which aggraded above sea level. Northwestward of the island, the shoal belt, on strike with ridge generation No. 1, extended through Cat Island Shoal-Tail of Square Handkerchief Shoal and Square Handkerchief Shoal. Here, the shoal belt took a southwesterly bend and reached the Mississippi mainland northeast of Point Clear.

Cat Island had been actively prograding when the St. Bernard subdeltas of the Mississippi River encroached on its immediate vicinity 3,000-2,300 yrs. B.P. (Frazier 1967). Our heavy mineral studies show that the delta, in all likelihood, never encroached on the island proper. However, its subaerial parts and its extensive shoaling effects blocked and dampened open Gulf wave energies east, south and west of the island. The new delta had also created the western portion of the present Mississippi Sound in the process. Change in the configuration of land and seas reduced or eliminated active nourishment of the east-west Cat Island segment through the shoals from western Ship Island. Eroded material from the eastern island end, instead of being moved westward as previously, was carried north and south and built into the North and South Spits. The spits now effectively shielded the east-west island segment from receiving any sand from the east and speeded up erosion on its northern and southern shores.

After the destruction of the proximal parts of the St. Bernard subdeltas, island erosion continued at an increased rate as wave energies reaching the island on the east increased again. Aside for the periodic regeneration of South Spit, the island is steadily losing subaerial surface area (approximate area at present: 9.3 sq km). This reduction is undeniably more serious than island area losses on the other barrier islands, following hurricanes. While the other islands, over longer periods of time may recoup their considerable losses through fair-weather gains, no sediment source is available under the present conditions for Cat Island to achieve this.

LITERATURE CITED

FRAZIER, D. E. 1967. Recent deltaic deposits of the Mississippi River; their development and chronology. Gulf Coast Assoc. Geol. Socs. Trans. 17:287-315.

HENRY, V. J. 1976. Results of beach nourishment using dredged material, Fort Massachusetts, Gulf Islands National Seashore, Mississippi (abst.), 101. First Conf. Sci. Res. in the Natl. Parks, 327 p.

MCGEE, W. J. 1890. Encroachments of the sea. The Forum. 9:437-449.

NELSON, H. F., and BRAY, E. E. 1970. Stratigraphy and history of the Holocene sediments in the Sabine-High Island area, Gulf of Mexico. 48-77. Deltaic Sedimentation. Soc. Econ. Paleont. and Mineralogists Spec. Publ. 15, 312 p.

OTVOS, E. G., JR. 1973. Geology of the Mississippi-Alabama coastal area and nearshore zone. The New Orleans Geol. Soc. 67 p.

_____. 1975a. Late Pleistocene transgressive unit (Biloxi Formation), northern Gulf Coast. Bull. Amer. Assoc. Petr. Geologists. 59:148-154.

_____. 1975b. Inverse beach sand texture-coastal energy relationship along the Mississippi Coast barrier islands. Jour. Mississippi Acad. Sci. (1973-1974), 19:96-101.

_____. 1976. Holocene barrier island development over preexisting Pleistocene high ground: Dauphin Island, Alabama. Geol. Soc. America Southeastern Mtng. Abstr. 239-340.

_____. 1977. Post-Miocene geological development of the Mississippi-Alabama coastal zone. Jour. Mississippi Acad. Sci. (1976), 21:

PHLEGER, F. B. 1954. Ecology of Foraminifera and associated microorganisms from Mississippi Sound and environs. Bull. Amer. Assoc. Petr. Geologists. 38:584-647.

_____. 1960. Sedimentary patterns of microfaunas in northern Gulf of Mexico. Recent Sediments, Northwest Gulf of Mexico. Amer. Assoc. Petr. Geologists, Tulsa, Okla. 267-301.

SWANSON, V. E. and PALACAS, J. G. 1965. Humate coastal sands of northwest Florida. U.S. Geol. Survey Bull. 1214-B, 29.

UPSHAW, CH. F., CREATH, W. B., and BROOKS, F. L. 1966. Sediments and microfauna off the coasts of Mississippi and adjacent states. Miss. State Geol. Survey Bull. 106:127.

U. S. ARMY ENGINEER DIV., CORPS OF ENGINEERS. 1971. National Shoreline Study. Regional inventory report, South Atlantic-Gulf Region, Atlanta. i-h14.

WALLER, T. H. and MALBROUGH, L. P. 1976. Temporal changes in the offshore islands of Mississippi. Water Resources Res. Inst., Mississippi State Univ. 109 p.

WALTON, W. R. 1960. Diagnostic faunal characteristics on and near a barrier island, Horn Island, Mississippi. Gulf Coast Assoc. Geol. Socs. Trans. 10:7-24.

ACTIVE GEOLOGIC PROCESSES PADRE ISLAND NATIONAL SEASHORE - IMPACT ON PARK MANAGEMENT

Christopher C. Mathewson and Robert M. McHam[1,2]

PADRE ISLAND NATIONAL SEASHORE

In 1962, Congress enacted legislation to obtain land on Padre Island and to establish Padre Island National Seashore. The National Seashore stretches some 105 km along the South Texas coast and provides camping, swimming, and fishing for visitors (Fig. 1). The National Park Service is charged with the responsibility of managing a geologically dynamic environment, providing for the development of potential energy deposits, increasing recreational uses and protecting the environment and wildlife habitat.

The island is presently open to most park visitors only at North and South Beaches and in the Malaquite Beach day use area. Because no roads have been constructed down the island, traffic must move on the beach. Little Shell and Big Shell Beach contain shell pockets which are impassable to conventional vehicles. As a result, a majority of the park visitors are confined to about 24 km of the entire 105 km of National Seashore. Since park visitation now exceeds 1 million per year, this heavy use must be distributed throughout more of the available Island space in order to protect the existing barrier island environment, but you might then "destroy" the whole island. A proposed master plan by the National Park Service calls for the closure of beach access and construction of a shell road behind the foredunes as far south as Yarborough Pass. Implementation of this plan and the success of its outcome can be improved through an understanding of the active geologic processes.

As part of a Sea Grant research project with additional support from the Sun Oil Company and the Padre Island National Seashore, a study of sediment transport mechanisms on both the island and in Laguna Madre was carried out.

AEOLIAN PROCESSES

In general, active geologic processes can be divided into two basic categories: 1) hurricanes, earthquakes and other irregular, intermittent events and 2) daily winds, waves and other regular, recurrent events. Hurricanes and storms are irregular in intensity and occur on an intermittent schedule, making them difficult to predict. Daily wind, on the other hand, is more regular in intensity and occurs more frequently, often having a cycle of a day or so.

Engineering works and park management decisions on Padre Island must contend with both categories of active processes. With respect to hurricanes, management decisions are usually limited to evacuation of personnel and to the closing down of operations. In terms of the engineering impact of hurricanes, structures can either be designed and built to withstand the storm or designed as sacrifice structures depending upon economic and environmental considerations. The net result of an irregular, intermittent event is the cost of repair once the storm has passed, costs which should have been incorporated into the design of the structure.

Hurricanes have a significant impact on the geologic environment of Padre Island. Hayes (1967), McGowen et al. (1970), and others have reported on the role of hurricanes as geologic agents. In general, a surge of high water accompanies hurricane passage and washes through low places on the island, cutting passes, eroding the beach and dunes, and flooding the back island flats. These processes will drastically alter the morphology of the island; the foredune ridge may be breached, new washover sands will cover the vegetated flats, and washover channels may sever the island into a chain of islands. Once the storm passes, however, the regular recurrent events once again become the dominant geologic processes. Recent work suggests that regular recurrent events active on Padre Island are the significant processes to be considered in park management decisions and in the design and construction of engineering works (Mathewson et al. 1975; Mathewson 1977).

Aeolian transport of well sorted, fine grained sand (0.11 mm) across the island has a significant impact on park management and planning because the "blow sand" associated with large dune fields increases maintenance costs, buries structures, and can make access impossible. This process should directly affect the economic considerations in any engineering design. Padre Island, in the area of the National Seashore, has large active dune fields covering many square kilometers that stretch from just behind the foredune ridge to Laguna Madre. Individual dunes within the fields may reach elevations of 4.5 m to 6 m above the elevation of the vegetated flats. Attempts to maintain an oil field access road through these fields have met with economic failure as have attempts to stabilize the dunes near the road. The temporary solution has been to reroute the road down wind of the fields. The relocated road however, will eventually need to be moved again and again until the road is either abandoned or built out into Laguna Madre on fill.

The impact of advancing dune fields has not yet been felt to any significant degree on oil and gas recovery installations or on park service structures, since these engineering works are of limited extent and, except for one installation, are not located at the appropriate sites. If management decisions are to be made relative to permanent structures and if continuous access is to be provided along the back of the island, the origin, migration patterns, and control of the active dune fields must be understood.

A detailed study by Mathewson and others (1975) of landward sand transport and changes in island morphology was carried out in the vicinity of Yarborough Pass, approximately 16 km south of South Beach (Fig. 1). Based on historical aerial photographs and field data, this study concluded that the large active dune fields in the Yarborough Pass area were formed through long-term aeolian processes rather than through hurricane processes

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alone as proposed by Boker (1953), Blankenship (1955) and Hayes (1967).

The development of dune fields in the Yarborough Pass area progresses through five stages (Fig. 2). The initial morphologic features of the barrier island include the beach, the foredune ridge, and vegetated flats which grade lagoonward into wind tidal flats. Sediment is deposited on the beach by wave action, sorted and transported by the prevailing southeast winds, and finally, deflected northward by the foredune ridge.

Aeolian transport across the island is inhibited when the foredune ridge and back island flats are stabilized by vegetation. However, hurricane attack of the foredune ridge strips away the stabilizing vegetation and forms a hurricane beach, allowing aeolian processes to become highly effective (Fig. 2-2). Hayes (1967) defined three types of foredune ridge breaches: "major hurricane channel, minor hurricane channel, and the total destruction of the foredune ridge for long distances (1 mile or more)". Mathewson (1977) proposed the term "major foredune breach" for the latter condition. In the case of the major and minor channels, the breach is narrow and heals within 6 years while the major foredune breach remains open. In the area of a major breach, hurricane waves form a hurricane beach (Fig. 3).

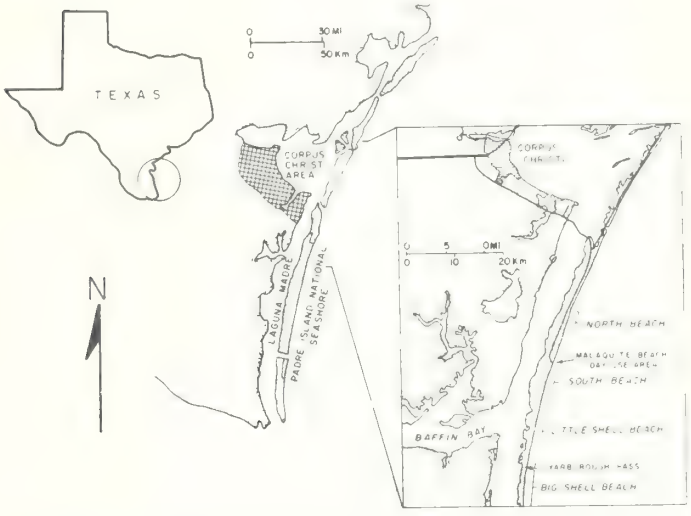

FIGURE 1. Location maps of Padre Island National Seashore and the study area.

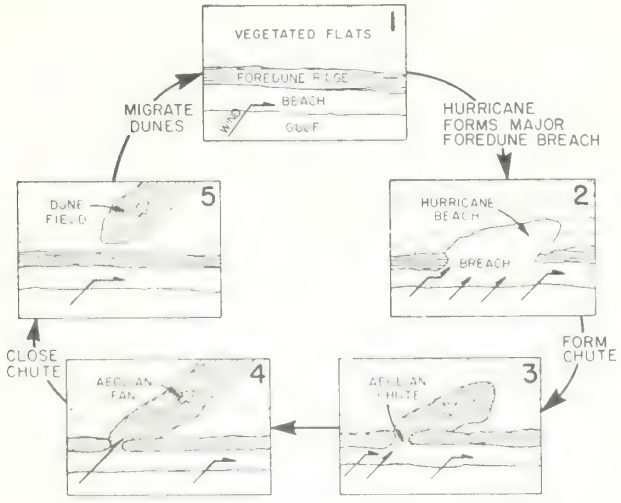

FIGURE 2. Schematic diagram showing the cycle of development of an Aeolian Fan and Fields, based on studies of historical airphotographs near Yarborough pass, Padre Island National Seashore. Initially a hurricane breaches the foredune ridge and forms a hurricane beach. The breach gradually heals until the chute forms. Continuous sand transport through the chute forms the Aeolian fan. Once the chute closes the dune field migrates downwind.

The hurricane beach is topographically higher than the surrounding flats and above the capillary fringe of the island freshwater lens. This higher elevation allows the sand to drain; thus, revegetation is slower and aeolian processes become the major transport mechanism. Reconstruction of the foredune ridge by aeolian processes through the development of coastal dunes as described by Bagnold (1941) and Fisk (1959), closes the major foredune breach by forming scattered dunes which eventually coalesce, except at the southern end. Here, high sediment transport and high wind shear apparently keep sand from being deposited (Fig. 2-3). An aerodynamically stable chute forms at this point and continues to serve as a conduit for the transport of sand through the foredune ridge, forming an active dune field (Fig. 2-4). Mathewson (1977) labeled the term "aeolian fan" for this type of dune field. At Yarborough Pass, the chute is generally aligned with the prevailing winds and has remained a transport route for windblown sand for more than 30 years. Figure 4 is an aerial photograph of an aeolian fan complex near Yarborough Pass as it appeared in 1974.

Eventually the chute closes due to encroachment of the vegetated foredune ridge (Fig. 2-5). Following the closing of the chute, the source of beach sediment for the aeolian fan is lost and the dune sand migrates across the islands as a dune field and eventually becomes the back island dunes.

The above model is based on study of historical photographs from the area of Yarborough Pass. In 1933, a hurricane formed both a major hurricane channel and a major foredune breach. Another hurricane in 1936, probably reopened the breach in the foredune ridge. The 1937, aerial photogeologic map shows that the washover fan and the major hurricane breach have not revegetated. By 1943, the hurricane washover fan sediments were stabilized by grasses, the foredune ridge was discontinuous and partially vegetated, and the hurricane beach ridge had reformed except for the southern end where the aeolian chute had developed. Between 1953 and 1973, sand was continually added to the aeolian fan through the chute, lengthening it in the down wind direction. By 1975, the chute had effectively closed and the aeolian fan had crossed the vegetated flats and encroached onto the wind tidal flats. Vegetation is now slowly stabilizing the head of the aeolian fan. As the sand in the aeolian fan continues to move lagoonward, it apparently will migrate onto the wind tidal flats and eventually form the back island dune. With a storm of the intensity of the 1933 hurricane, the chute may be reopened or the dune wall be breached, initiating the cycle again.

Grain size data collected from the aeolian fan at Yarborough Pass further support the process described in the photogeologic analysis. Figure 5 is a Dowling (1974,1977) diagram of the grain size distribution along a series of profiles starting at the first offshore bar, crossing the beach and extending through the aeolian chute to the wind tidal flats at the back of the island (Fig. 6).

These results show that the sand in the aeolian fan and wind tidal flats is normally distributed and transported by aeolian processes. Note the similarity in the characteristics of the sand in

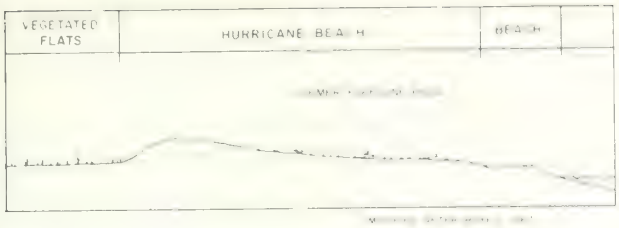

FIGURE 3. Diagrammatic cross section of a hurricane beach.

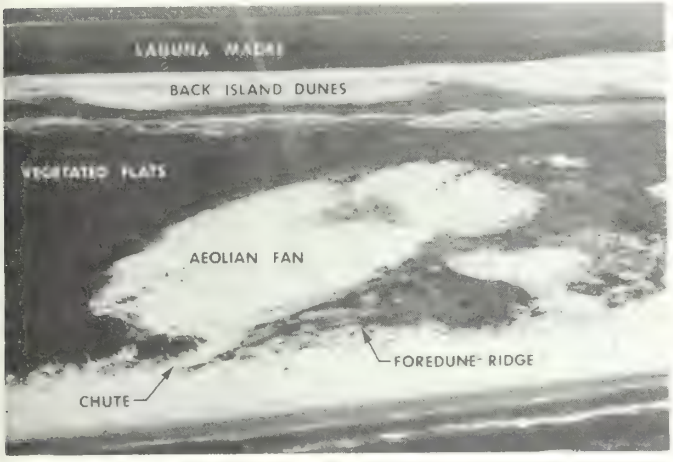

FIGURE 4. Oblique aerial photograph of the Yarborough Pass area, aeolian fan complex as it appeared in 1974. Note the identified geologic features.

FIGURE 6. Map of transects along which samples were collected to construct the Dowling Diagram in Figure 5.

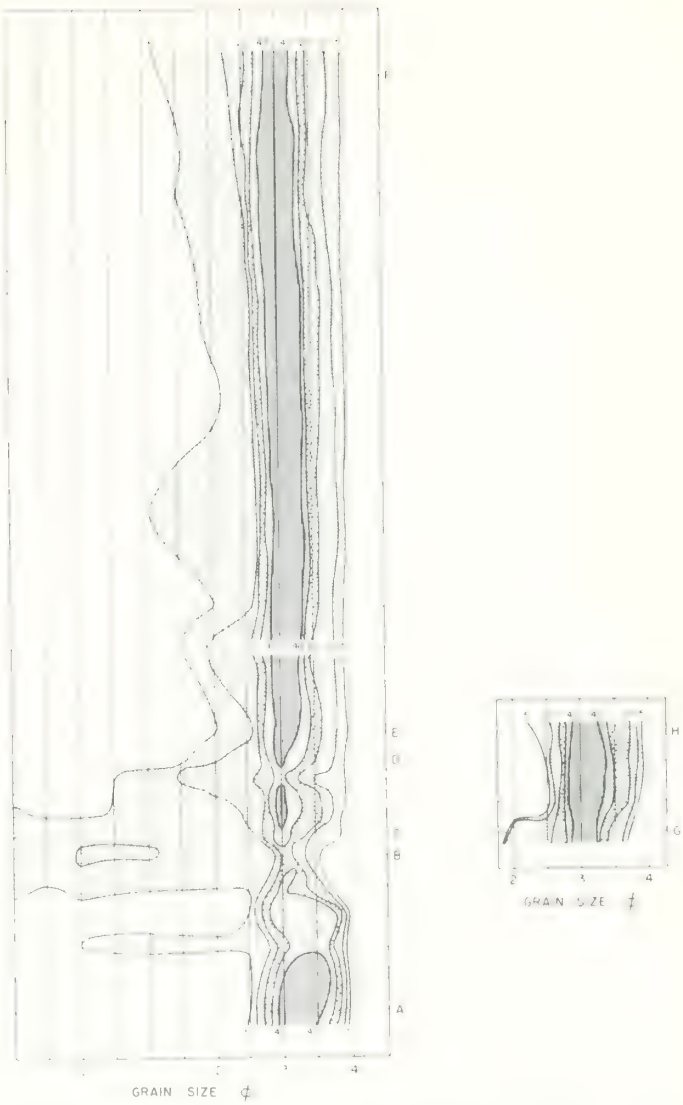

FIGURE 5. Dowling Diagram of the distribution of sediment size along a transect from the first bar offshore to the wind tidal flats. Note the influence of aeolian sorting. Figure 6 shows the transect on a map.

the foredune ridge (profile G-H) to that in the aeolian fan. The sharp shift to a coarser grain size in the head of the aeolian chute is indicative of higher wind shear caused by the funnel shape of the aeolian chute. These sedimentary data are compatible with measured wind velocities, in which the wind velocity at the head of the chute was 2 to 5 m/sec higher than on the crest of the neighboring foredune. The authors believe that the back island dunes and aeolian fans on north Padre Island are the result of the same process; aeolian transport initiated by hurricane formation of a major foredune breach.

CONCLUSIONS

Park management decisions and engineering construction in the Padre Island National Seashore must consider both the irregular, intermittent events and the regular, recurrent events, since they are interrelated. Hurricanes are a "rare" event that provide limited design alternatives for any park improvements. Structures should be designed and built to either withstand flooding, wave attack, and high winds or be sacrificed to the storm. Management choices should be based on economic considerations, cost-risk analyses, potential environmental hazards and the goals of the park plan.

The effect of aeolian transport and dune field migration must be considered in the long-term costs of maintenance. Roads and structures must be designed and built in such a manner that they can either be sacrificed to the dune field, removed and relocated when necessary, or provided with protective covers to prevent structural loss. These choices require that the decision maker understand the mechanisms of the aeolian fan and design accordingly. Alternative choices to structural design solutions are to modify the geologic processes by closing the chute, removing the aeolian fan for beach nourishment or other uses, or stabilizing the dunes. These alternatives must be selected as a function of the cost-benefit of each.

Rebuilding and repair after major storms should consider the post-storm island morphology with respect to the potential for the formation of aeolian chute and fan complex. It is impossible to predict the site of the next major hurricane breach in the foredune ridge, however, once breach occurs the location of the related aeolian chute and fan can be predicted if it should develop. Thus, post-storm reconstruction should consider the effect of aeolian transport as an economic parameter in the management decision.

LITERATURE CITED

BAGNOLD, R.A., 1941. The Physics of Blown Sand and Desert Dunes, Morrow, New York, 265 p.

BLANKENSHIP, W.D., 1953. Sedimentology of the outer Texas coast: Univ. Texas, Master's thesis, 72 p.

BOKER, T.A., 1953, Sand dunes on northern Padre Island: Univ. Kansas, Master's thesis.

DOWLING, J.J., 1974, A technique for correlation grain size distributions, Abstract, Transport Mechanisms in the Nearshore Environment Conf., Mystic, Connecticut.

DOWLING, JOHN J., 1977, A Grain Size Spectra Map, Journal of Sed. Pet., v. 47, No. 1, 281-284 p.

FISK, H.N., 1959, Padre Island and the Laguna Madre flats, coastal south Texas: 2nd Coastal Geog. Conf., Louisiana State Univ., Baton Rouge, 103-151 p.

HAYES, M.O., 1967, Hurricanes as geological agents: Case studies of Hurricanes Carla, 1961 and Cindy, 1963; Univ. Texas, Bur. Econ. Geology Rpt. of Investigation 61, 54 p.

MATHEWSON, C.C., 1977, Beach Washouts, an Adverse Effect of Artificial Dune Construction, Bulletin, Assoc. of Engrg. Geol., Vol XIV, No. 1.

MATHEWSON, C.C., CLARY, J.H., STINSON, J.E., II, 1975 Dynamic physical processes on a South Texas barrier island-impact on maintenance: Ocean 1975, Conf. on Engrg. in the Ocean Environment and 11th Annual Meeting of the Marin Technology Society, San Diego, California, September, IEEE Publication, 75 CHO 995-1 OEC, p. 327-330.

GEOLOGY, PARKS AND OIL: ENERGY WITH PRESERVATION?

John A. Barnett[1] and Raymond Herrmann[2]

Responding to a request from the American Association of Petroleum Geologists' (AAPG) Environmental Geology Committee to participate in the "First Conference on Scientific Research in the National Parks," a seminar was arranged to present and discuss the views of petroleum geologists regarding geological research in the national parks.

On previous occasions, this AAPG Committee had discussed the difficulties of obtaining permits to do limited scientific field studies in the national parks. The committee had been concerned about the lack of a uniform National Park Service policy regarding geological field work and felt this may be due to a lack of understanding of the objectives and methods of such research.

The joint seminar served to summarize the objectives and methods of geological field work, aired the reasons why industry geologists (in addition to those from government and universities) believe they should be allowed to do field work in parks, enumerated the benefits that the AAPG feels would accrue to the public from such studies, and called for uniform guidelines for geological research in National Park System areas.

THE PETROLEUM INDUSTRY POSITION

Some geologists have no trouble at all when entering National Park Service areas to accomplish their research. However, when it is necessary to utilize heavy equipment or work in some parks such as Grand Canyon and Yellowstone, the existing permit system and regulations become quite complex as viewed from the perspective of the petroleum geologists.

Collecting permits, or special use permits, issued by the National Park Service for research activities, are generally requested by scientists representing educational institutions. One reason for approving such requests is the expectation that the results of research would help in the understanding or preservation of park resources. A few requests from private industry, where they were judged by the National Park Service as not disturbing park resources, have also been approved.

Oil and gas production is a reality on some National Park Service lands, where leasing and production activities predate the establishment of the area. Petroleum people feel that they are making a successful effort to not adversely affect park values in these areas. They indicate that there are other park lands where exploration for oil and gas might be fruitful. The sentiment of the entire industry seems to be that this can be done without contravening the National Park Service mandate of preservation.

Industry is not requesting a mass opening of all National Park lands for leasing or drilling. What is of importance, according to them, is that the oil industry has its own popular mandate to search for oil and gas in order to achieve national goals of reduced dependence on foreign sources. The industry has developed methods that were unknown, or economically impossible, just a few years ago. Further, they assert, these methods do not pose threats to the environment--including parks.

Oil industry people feel that there are geological "clues" locked up in National Park lands; clues that may help in the search for oil and gas *outside* of the parks. Measurements of geological section, paleontological studies, quadrangle mapping, or plane tabling activities in a park are the only ways to uncover this geological evidence. The industry feels that up to now, denial of permits for testing has been arbitrary and inconsistent, and too dependent on the vagaries of individual Park Service personalities.

They have observed that superintendents of neighboring parks have diametrically opposed viewpoints about identical permit requests. Obviously, they say, park resources differ, and what may be reasonable in one park may be destructive in another. What they suggest, however, is one policy and guideline that minimizes "knee jerk" denials by superintendents with a strong anti-industry bias.

Industry people report that entry to some parks has been denied for any company activity on grounds that the purpose of parks is not to accommodate private industry, or any form of commercial exploitation. This position has been expressed by many high-ranking Park Service personnel, according to the industry. In other parks, they report, geological personnel have been given special tours and collecting permits have been issued freely.

The industry sees contradictions in policy. They cite filming of the television production "Sierra" as a blatant commercial use. They also ask, "how many movies have been made on National Park lands?" Uses that oil companies suggest, they insist, are less destructive than the activities of filming companies. They note that measuring sections involves two or three men, some surveying equipment, and a method of transportation--jeep, pickup truck, horses, or helicopters. They compare this "equipment" impact with that of motion picture productions and find little difference.

According to the industry, surface geological crews have sometimes been given access to a National Park Service area, but only on foot. They were not permitted to leave paved roadways and they could work only in areas where they were not likely to be seen by visitors. Worthwhile research under those conditions was impossible, they feel. They say that their investigations, including core hole drilling, would not appreciably affect park resources.

Seismic activity is done generally only in an area with real drilling prospects. It is expensive and has some potential for terrain damage. The industry feels, however, that there are situations where seismic lines would not permanently damage the resource. Oil companies want

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a yardstick of "reasonable consideration" applied to their requests to examine National Park Service lands.

In summary, the industry asks the National Park Service for 1) more uniformity in standards for issuing permits, 2) more cooperation in granting "in park" surveys to support "outside the park" explorations, 3) less rigidity and "knee jerk" responses from some managers when a request for research is made, 4) a system to "safeguard" results of research, and 5) the infusion of an attitude of "reasonableness" into managerial estimates regarding the probability of impact of suggested research.

THE NATIONAL PARK SERVICE POSITION

Conservationists, including many in the National Park Service, are sensitive to the dilemma of the oil industry. However, the National Park Service feels that industry requests must be addressed in the context of the legal and ethical responsibilities of the resources manager. He is entrusted with the protection of the park, first and foremost.

National Park Service managers believe clearly that designation as a National Park System area is the greatest degree of protection that the Congress can legislate. Areas are protected because of outstanding natural and historic significance. Public land protection, where preservation is a primary responsibility, extends to less than 1 percent of the land area of the United States. Explicitly and implicitly, these areas are considered to have historic or natural values more important than the exploitative value of minerals or other consumptive uses of resources, such as water development projects, timber harvesting, and agricultural production. Many National Park Service managers believe that the "intent of Congress" in most park legislation mandates a strong, protectionist stance "against all comers."

THE DICHOTOMY

A number of critical issues affecting interaction between the oil industry and National Park Service were identified. They are reviewed with no expectation of easy resolution.

1. Who sees the results of research. immediate release, availability, and display of data collected in parks is not always considered "feasible" by oil companies. However, based on National Park Service regulation, disclosure is usually required as a pre-requisite for a National Park Service collecting permit. Research by private industry on public land cannot be condoned if the information gathered is withheld from the managing agency.

Oil companies argue that, given the expense of collecting geophysical data, it is not feasible to supply the results of investigations to the managing agency and risk losing an economic prospect. Acceptable solutions for cases where exploration activities are permitted in a National Park Service area may emulate the procedures employed by the United States Geological Survey.

2. Environmental Impacts of Industry Research. The industry call for in-park research to support outside-the-park exploration has merit in the view of some National Park Service people. A stratigraphic prospect of economic potential can sometimes be determined only by obtaining structural and stratigraphic data from an area far larger than the possible drilling location. A totally continuous geological picture is needed, according to the industry geologist, to complete an analysis of a major oil prospect. This is sometimes not possible if an area as large as some national parks is omitted from analysis. Studies of this kind may be proposed from some National Park Service areas with more frequency.

Stratigraphic research, as opposed to core or exploration drilling, requires some sampling and detailed measuring of units, but is often no more destructive to resources than public visitation. However, other research that requires drilling, extensive sampling, or other operations is sometimes destructive, in the National Park Service view, and demands careful definition of purpose and very close oversight by the National Park Service.

Access with equipment can be destructive to terrain and tranquility of wilderness areas. In many park areas, vehicles are excluded to minimize impacts. National Park Service managers are concerned about helicopter use in some parks, and permit them for emergencies only. Industry activities are *not* emergencies, according to National Park Service managers, and a real question is, "how can we justifiably allow oil companies to use helicopters and vehicles in those areas where even our *rangers* are not so permitted by law or policy?"

3. Research or Exploration and Production. There is a large body of non-exploratory *research* being undertaken by oil companies. These projects can involve the study of geologic processes as they relate to the occurrence and concentration of economic oil. Research of this type by private firms could be permissible as a matter of policy. Activities in this category should be evaluated separately from those involving exploration and production. Review of an acceptable research proposal will simplify the evaluation of these activities. One perceives, however, that if industry research develops economic mineral resources, whether oil or some other commodity within or near the boundaries of a National Park area, the conflicts which accompany production will follow.

4. Regulations. The language of Title 36, *Code of Federal Regulations*, Paragraph 2.25, cannot be bent very far without its abrogation--the implication is strong that oil company research would be a non-permissible park activity, in most cases. To lawfully permit oil company activity of the type and on the terms desired, the Code would need alteration.

Laws that may affect geologic activities are: Public Law 91-190, The National Environmental Policy Act of 1969 (83 Stat. 852); Public Law 93-205, The Endangered Species Act of 1973 (87 Stat. 884); The National Park Service Organic Act of 1916, as amended, (39 Stat. 535); Public Law 93-502, The Freedom of Information Act of 1970 (88 Stat. 1561, 5 USC 552); and the individual laws creating and authorizing each unit of the National Park System.

In each case where oil exploration or oil production is authorized in a park by legislation, the Park Service complies with the legislation. Regulations have been proposed [(36 CFR, Part 9) Mining and Mining Claims, Interim Regulations and proposed Comprehensive Regulations, Federal Register (Vol. 41, No. 219), November 11, 1976] to implement Public Law 94-429, National Park System, Mining Activity Regulations (16 USC 1901), thus insuring that all mining operations in areas of the National Park System are conducted in a manner that prevents or minimizes damage to the environment and other resource values. Parks with legislatively authorized mineral activities

may also have existing or proposed regulations which stipulate environmental protection measures required of permittees involved in mineral exploration and development.

CONCLUSION

Actions that regulate human activities almost always create conflict. The need for geologic research and exploration by petroleum geologists, on the one hand, and National Park Service perception of its lawful and ethical responsibilities on the other, have created a conflict exacerbated by the energy crisis. The pressures for energy independence are increasing. At the same time, the National Park Service is under heavier pressure to protect parks from environmental degradation and "threats" from commercial exploitation.

The dilemma demands openness, frankness and candor if solutions are to be hammered out, and discussions have barely begun.

GLACIAL GEOLOGY OF RECENTLY DEGLACIATED BEDROCK AREAS[1]

B. Hallet[2]

Areas recently exposed by the retreat of cirque glaciers in Glacier National Park, Montana, were studied in the context of the modern glacier sliding theory, to elucidate the processes that are active at the bases of these glaciers. This study can be subdivided into three parts: subglacial chemical exchange; striations and basal ice flow; and roughness of glacier beds and calculated sliding velocity.

Thin coatings of calcite, formed by subglacial precipitation of $CaCO_3$, patchily cover most areas uncovered by the retreat of each of five glaciers visited, and are particularly well developed below the Blackfoot Glacier. The subglacial concentration and precipitation of solutes are intimately related to basal sliding; on one hand solutes concentrate because of the sliding process, and on the other, the sliding velocity may be slowed by solutes because of their effect on the thermal regime of the basal temperate ice.

Striation patterns indicate that minor bed irregularities often cause major deviations in the basal ice flow. They also occasionally reveal circulating, eddy-like flows above bedrock concavities, suggesting that basal flow and sliding may be considerably more complicated than generally recognized.

Lastly, the roughnesses of glacier beds were analyzed quantitatively because they control the sliding velocity. Spectral analyses of a topographic profile surveyed near the Grinnell Glacier suggest that theoretically the glacier ought to slide less than one meter per year. In view of measured surface velocities of about 15 m/year near the terminus, the theory appears to underestimate the sliding velocity.

INTRODUCTION

The flow of glaciers and the general imprint of glaciers on the landscape have long been studied, and are relatively well understood. However, numerous specific questions about the mechanics of glacier motion, as well as glacial erosion and deposition, remain largely unsettled. For example, the rate at which a temperate glacier flows cannot presently be predicted in a quantitative way mainly because the rate of glacier sliding is difficult to evaluate; although quantitative theories treat the glacier sliding problem (Nye 1969; Kamb 1970), they do not readily include the important effect of water at the glacier-bed interface because little is known about how and how much water is distributed subglacially, questions of considerable glaciological interest (Weertman 1972; Shreve 1972; Nye 1973a, 1976).

Similarly, the fundamental process of glacial erosion is only qualitatively understood. Although abrasion and quarrying have long been recognized as erosional processes active under glaciers, the relative importance of each is still in question, and the underlying mechanics are only now starting to benefit from the modern glaciological views of near-bed processes (Boulton 1974; Morgan and Boulton 1975). Moreover, other processes including subglacial fluvial erosion (Vivian 1975) and subglacial chemical erosion (Vivian 1975; Hallet 1976a) have recently come to light as being potentially important, often having a greater effect on the glacier bed than other erosional processes.

It is these fundamental processes active near the glacier bed, which control glacier sliding and the geomorphic effect of glaciers on the landscape, that have been the subject of our research.

Our field studies, as well as those of others interested in extant glaciers, are particularly dependent on close cooperation with the National Park Service because much of the North American high alpine terrain where glaciers occur is included in National Parks. This is not surprising, however, because glaciers are largely responsible for giving the landscape the typical high alpine character that renders many mountainous areas so attractive and aesthetically pleasing and, hence, such likely candidates for National Park status. A close interaction between the National Park management and glaciologists and glacial geologists is therefore essential, not only in rendering scientific field studies possible, but also in helping provide a deeper understanding of the nature and mode of formation of many of the spectacualr park landscapes.

METHOD

In 1972 we began a systematic field study of recently deglaciated areas in the Northern Rocky Mountains. Our approach consists of making detailed observations of freshly glaciated rock surfaces in an effort to extract information about the processes active at or near the base of temperate glaciers (these glaciers are at their melting point throughout except for a surface layer that can freeze in the winter). For example, glacial striations, crescentic fractures and other small scale erosional features record, in considerable detail, the flow patterns of former basal ice. The details of basal ice flow past bed irregularities of various shapes and sizes are of considerable interest because 1) they must be incorporated in valid models of glacial erosion and deposition, and 2) they offer a means of checking whether the modern sliding theory adequately predicts basal ice flow near uneven rock surfaces.

Except for a number of chemical deposits and dissolutional features resulting from chemical processes occurring at the glacier-rock interface,

[1]I wish to sincerely thank Professors R.L. Shreve and W.E. Reed; their expert advice, their interest and encouragement helped me most significantly during the early phases of this work. It is a pleasure to also acknowledge the assistance of my wife, Amy, who provided considerable critical assistance during the field studies, as well as in all other facets of this work. Aram Anthony and Alex Heyneman also provided much field assistance for which I am very grateful. The general cooperation of the U.S. National Park Service and the Canadian Bureau of Indian and Northern Affairs was essential for the successful completion of the field work and is greatly appreciated. Much of the work reported here was supported by the Earth Science Section of the National Science Foundation (Grant GA-40497X).

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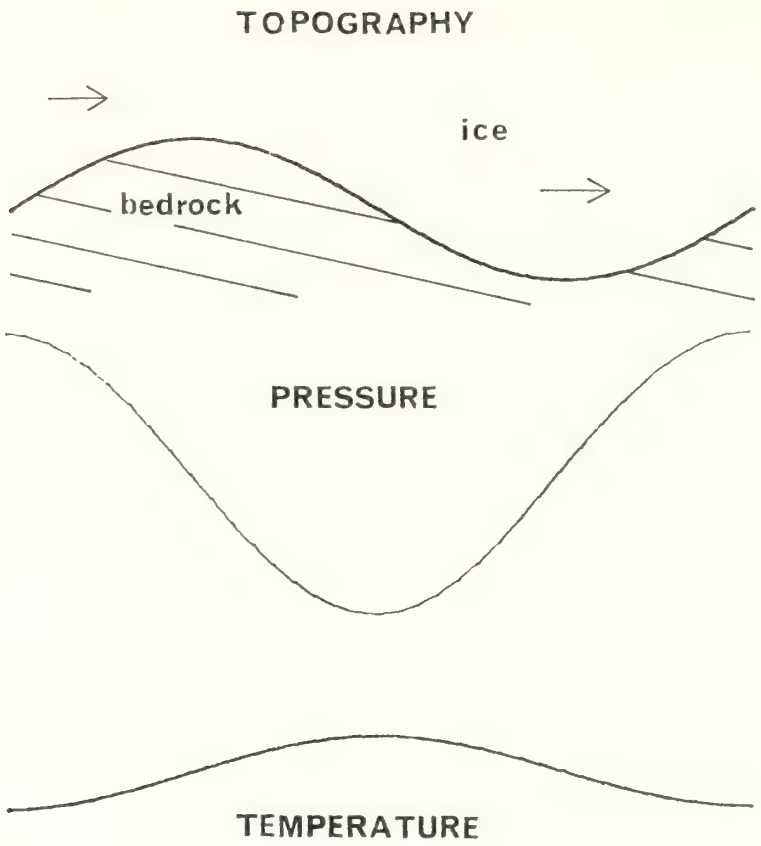

FIGURE 1. (upper) Schematic model of temperate ice sliding over a sinusoidal bed from left to right. (center) Resultant pressure distribution. (lower) Resultant temperature distribution for ice at its melting point. The coordinates in this figure are such that pressure and temperature increase upward.

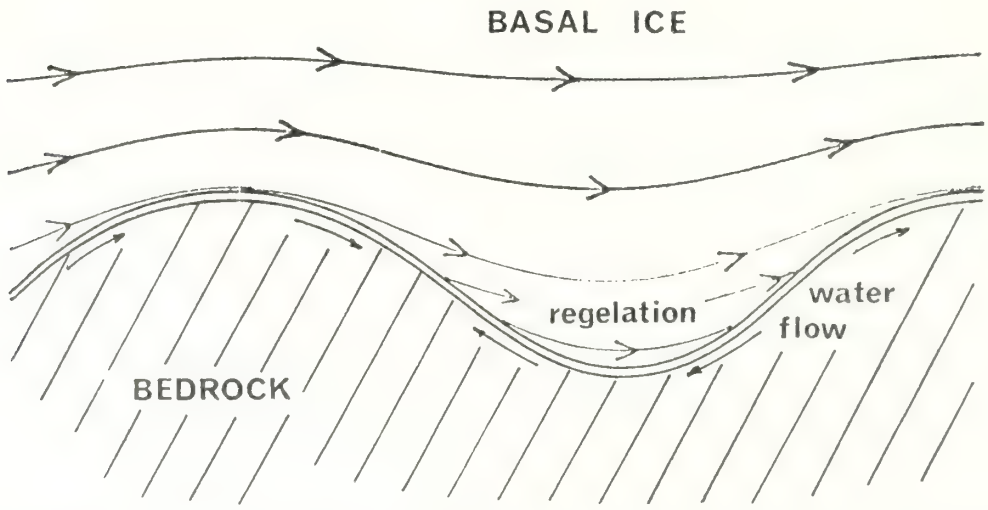

FIGURE 2. Streamlines characterizing glacier sliding over a sinusoidal bed with a wavelength of about one half meter. Temperate ice slides past bed obstacles by viscous deformation, as well as the regelation process, which involves pressure-melting and refreezing along stoss and lee sides respectively. Meltwaters flow from areas of enhanced pressure along stoss surfaces toward adjacent lee areas, where the pressure is lower, along a microscopic subglacial film.

as described below, most glacial features examined in our field work had already been extensively studied in numerous areas. However, our work differs from practically all previous studies of glacier-related small scale erosional forms in that it is conducted in the context of the modern understanding of glacier sliding and other near-bed processes.

Ideal localities for studying freshly glaciated bedrock are those where extensive bedrock areas have recently been uncovered by glacial retreat. Several such localities were found in the Rocky Mountains of Canada and Montana, U.S. All of the glaciers in this region have been steadily retreating since the last neoglacial advance around A.D. 1850, and many of them have exposed extensive areas of glaciated bedrock. Moreover, the rock types in this region, principally shallow marine carbonates and argillites, are particularly well suited for this study because they are relatively soft; hence they tend to record a remarkably complete set of striations, ranging from fine hair-like smears to deep scratches. Finally, other advantages of working in this area are that the glaciers are relatively accessible, and many of them have already been studied extensively, thereby providing a peripheral data base that facilitates the interpretation of our results.

STUDY SITES

Our field studies were conducted in the vicinity of eleven Rocky Mountain glaciers, most of which were located in Glacier National Park, Montana, U.S. and in Banff and Jasper National Parks, Alberta, Canada. Although this paper summarizes the results of the field studies undertaken at the Grinnell, Blackfoot, Jackson, Sperry, and Clements glaciers in Glacier National Park, Montana, many of the findings are similar to those based on field work in Banff and Jasper National Parks. All of the glaciers studied are small cirque glaciers that extended several hundred meters below their present margins about a century ago, and much farther down the valleys during the Pleistocene glacial period. All the processes discussed below are intimately related to the sliding of temperate glaciers, hence the modern glaciological model of sliding is briefly reviewed before presenting the three major facets of our study, which are: 1) subglacial chemical exchange, 2) striations and basal ice flow, and 3) glacier bed roughness and calculated sliding velocity.

GLACIER SLIDING

For simplicity consider temperate ice (ice always at the melting point) flowing over a sinusoidal surface as shown in Fig. 1a; the pressure tends to be greatest in the center of the upglacier (stoss) sides and smallest in the center of downglacier (lee) sides, as schematically shown in Fig. 1b. Inasmuch as the melting temperature of ice decreases with increasing pressure, the highest and lowest temperatures would be expected along lee and stoss sides respectively, assuming the ice is temperate throughout (Fig. 1c). This temperature distribution and heat flow pattern gives rise to a sliding mechanism unique to temperate glaciers; in addition to deforming viscously around bed obstacles, temperate ice can pass by them by pressure melting along stoss surfaces, which produces waters that flow to, toward adjacent lee surfaces where they refreeze to form regelation ice (Fig. 2). Because temperate ice is at its melting point, an influx of heat along stoss surfaces simply melts the ice there, and an equal outflux of heat from lee surfaces causes the water so produced to refreeze in lee areas. The importance of this pressure melting and refreezing mechanism decreases as the sizes of bed obstacles increase because the distance between lee and stoss sides, the heat sources and sinks respectively, increase thereby decreasing the heat flow across bed obstacles. This mechanism is as important as viscous deformation for sliding by obstacles approximately one half meter in size, and more so for smaller ones. Detailed and comprehensive discussions and quantitative theoretical models of the sliding phenomenon can be found in Nye (1969) and Kamb (1970).

SUBGLACIAL CHEMICAL EXCHANGE

The most enlightening and novel result of our study is that chemical processes are clearly active at the glacier-rock interface; in certain areas underlain by carbonate rocks, they often seem to modify the glacier bed more extensively than does glacial abrasion.

Thin superficial chemical deposits and associated solutional features, which are widespread on calcareous bedrock exposed by retreating glaciers, clearly indicate that chemical processes are active at the base of temperate glaciers. The subglacial chemical deposits generally occur as thin greyish-white coatings that patchily cover the upglacier sides of lee surfaces, of small cracks and other bed depressions (Fig. 3). In certain localities, however, they commonly take on more complicated shapes such as elongated columnar spicules, occasionally resembling stalactites, which generally point in the former ice flow direction (Fig. 4). Solutional furrows, often closely associated with the deposits, tend to be oriented perpendicular to the former ice flow direction but their ends often curve down-glacier (Fig. 4).

The extensive bedrock area exposed near the terminus of the Blackfoot Glacier is covered with the most spectacular signs we have ever seen of subglacial chemical processes. Many portions of rock surfaces are entirely covered with thick calcite coatings, heavily furrowed and fluted parallel to the former ice flow direction, and deep solutional furrows are etched into the bedrock. On a scale of several meters, parts of the former glacier bed commonly appear to be covered with coalescing U-shapes, concave down-glacier; the interior of the U consists of a bedrock protuberance heavily dissected by solutional furrows, and the exterior consists of a bedrock trough choked with massive calcite deposits (Fig. 5). Moreover, many of the deposits in this area are particularly well developed with stalactite-like growth several centimeters long, generally paralleling the former ice flow direction (Fig. 4).

In brief, subglacial chemical processes are a direct consequence of glacier sliding, particularly of the pressure-melting-refreezing mechanism. Meltwaters pressed in intimate contact with the bedrock tend to dissolve it. The solutes so derived, as well as those originally present in the basal ice, are carried by the flowing water to lee surfaces where the refreezing takes place. As this water refreezes, solutes tend to be systematically rejected into the liquid phase by the growing ice, much in the same way as has been observed in experiments with various ionic solutions (Hallet 1976a). The solute rejection that is characteristic of freezing, and hence must occur in the sliding process, is therefore responsible for the enrichment and eventual precipitation of solutes in the lee of obstacles overridden by sliding temperate glaciers.

FIGURE 3. Thin lightly colored carbonate coatings formed by subglacial precipitation of $CaCO_3$, near the terminus of the Grinnell Glacier. Ice was formerly sliding from right to left, parallel to the 30-cm-long pointer, over a surface consisting of stromatilitic mounds in the Siyeh Formation. Inasmuch as the coatings are systematically localized on the down-glacier side of bedrock protuberance, they are useful indicators of the former ice flow direction.

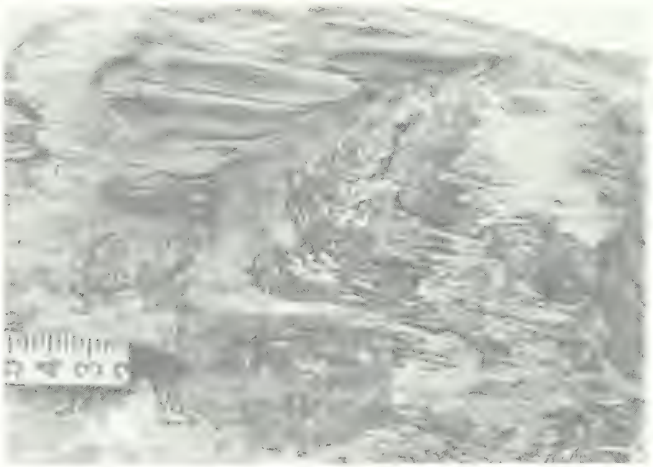

FIGURE 4. Thick subglacial calcite deposits in the Blackfoot Glacier area, with well developed columnar spicules and flutes parallel to the ice flow direction, indicated by the pointer. Note the solutional furrows etched into the bedrock; they tend to be perpendicular to the ice flow direction, as can be seen near the pointer tip. The numerals on the pointer represent 0.1 ft (3.05 cm), and the strike and dip symbols represent the nearly vertical orientation of the rock surface.

STRIATIONS AND BASAL ICE FLOW

The early work of Demorest (1938) inspired our initial interest in glacial striations and striation patterns. While studying the bedrock recently exposed by the retreat of the Clements Glacier (Glacier National Park, Montana), he observed an intriguing striation pattern that suggested that debris-laden ice flowed in an eddy-like manner. Such a behavior is remarkable, particularly in view of the high effective viscosity of the ice and slow flow rates.

Although unable to relocate the particular outcrop described by Demorest (1938), we found very similar striation patterns below the Grinnell Glacier. Of particular interest is one pattern that recorded ice flow past a set of rock surfaces forming an interior corner (Fig. 6a). Whereas the low lines of former basal ice are in general readily revealed by striations, it is usually not possible to determine unambiguously in which of two possible directions, parallel to the striations, the ice was flowing. This ambiguity is particularly problematical in attempts to interpret complicated striation patterns like the one pictured in Fig. 6. The presence of minute patches of the subglacial calcite deposits, systematically situated at the lee of small surface protuberances or at the upstream side of bedrock depressions, did however provide reliable indication of the local ice flow direction at the sites where the arrows are shown in Fig. 6a and 6b.

FIGURE 5. Entire surface of former glacial bed covered with clear signs of glacial precipitation and dissolution. The surface patterns resemble coalescing U-forms concave downglacier. The interior of the U-forms consist of rounded rock protuberances whose stoss sides are deeply etched by dissolutional furrows, and the exterior is delineated by thick deposits that partially fill bedrock grooves. The width of the picture represents about 2 meters.

This striation pattern suggests that former basal ice was sliding off a ledge and impinged upon a nearly vertical surface. Whereas the upper part of the ice was deflected upwards and continued in the general ice flow direction, the lower part was deflected downward toward the adjacent lower surface, along which it subsequently flowed in the upglacier direction toward areas of lower pressure. The continuous flux of ice downward and backward eventually forced ice to move back upward along the ledge, where the ice first separated from the bed. This ice flowing upward became partially coupled with the general ice stream, flowed downglacier, and may perhaps have been recycled through this eddy-like flow. The term closed-cell flow appears more appropriate for the inferred basal ice flow pattern because it does not necessarily connote turbulence; the effective Reynolds number for basal ice flow precludes turbulent flow in the conventional sense; the inertial terms are clearly insignificant. Closed-cell flows at low Reynolds numbers are, however, possible (Weiss and Florsheim 1965) and have apparently been observed in slow experimental deformation of ice (Kamb 1972). Striations patterns indicate clearly that similar closed-cell flows also occur at the base of temperate glaciers, when the surface geometry of the glacier bed and its relation to the ice flow direction is suitable.

In addition to revealing the often complicated details of basal ice flow, striations are of considerable interest because they demonstrate that basal ice flow is extremely sensitive to minor bed irregularities, inasmuch as these often cause major deviations in the basal ice flow and consequent striation patterns. Such marked response of the basal ice to minor stress fluctuations may reflect nonlinear viscous behavior of the basal ice. Moreover, the local presence and absence of striations on freshly deglaciated surfaces shows where basal ice was sliding in intimate contact with the bed and where it was not, and hence provides a means of evaluating the amount of local separation between ice and bed, known as cavitation. Data on the extent of subglacial cavitation are extremely important because at present little relevant data exist and yet this is one of the principal parameters controlling the sliding rate of temperate glaciers.

BED ROUGHNESS AND GLACIER SLIDING

The rate at which glaciers slide over their beds is dependent, in part, on the effective bed roughness. The sliding theories of Nye (1969) and Kamb (1970) treat the problem quantitatively and show precisely how the bed roughness affects the sliding rate. These theories suffer, however, from the lack of supportive data because actual verification of the theory could not be made without quantitative topographic measurements of glacier bed surfaces. In 1973, we surveyed points 1/2 ft (15.2 cm) apart along a 250 ft (76.2 m) topographic profile parallel to the general direction of former ice flow in front of the Grinnell Glacier.

Spectral analyses were performed on this topographic profile, shown in Fig. 7, as well as on two others measured near the Pyeto and Athabasca Glaciers in the Canadian Rocky Mountains. The analyses suggest that if the Grinnell Glacier advances over the measured rock surface, it would slide less than one meter per year for typical values of basal shear stress and ice viscosity of 1 bar and 1 bar-year, respectively (Hallet 1976c). Inasmuch as it is likely that the roughness of the bed presently under the Grinnell Glacier is similar to that of the one we measured, the theory

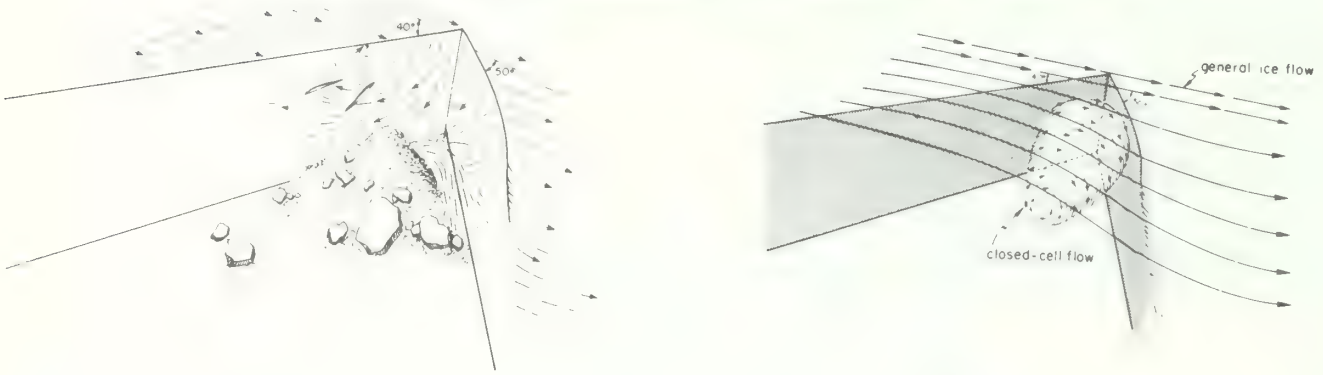

FIGURE 6. (upper center) Pattern of striations, near the terminus of the Grinnell Glacier, resulting from ice formerly sliding from left to right, parallel to the 30-cm-long pointer, and being deflected into a subglacial cavity. Chalk marks delineate striations and arrows indicate where the direction of ice flow could reliably be deduced. (left) Representation of striation pattern and distribution of directional indicators. (right) Schematic representation of former ice flow, showing inferred separation between general ice flow and the closed-cell flow.

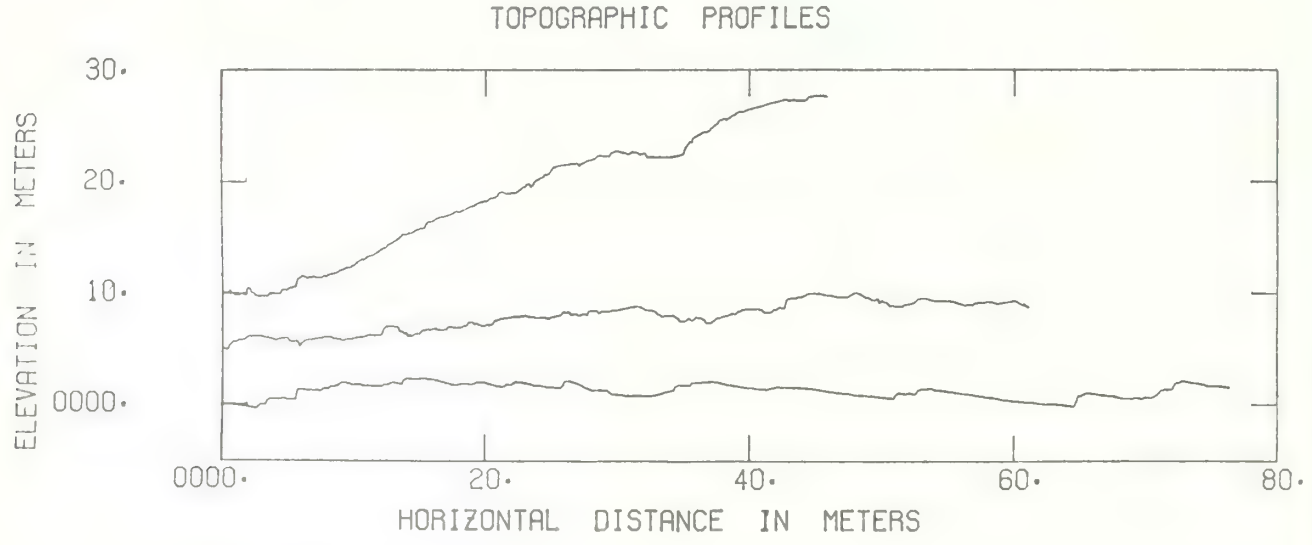

FIGURE 7. Topographic profiles of former glacier beds measured parallel to the general ice flow direction. The lower profile was surveyed near the terminus of the Grinnell Glacier; the ice formerly flowed from right to left. The center profile was measured near the Peyto Glacier, Banff National Park, and the upper one near the Athabasca Glacier, Jasper National Park, Alberta, Canada.

may underestimate the sliding velocity; surface velocities of about 15 m/year have been measured near the glacier's terminus, where the surface velocity results largely from basal sliding.

In an attempt to take into account local cavitation, spectral analyses were performed on the Grinnell topographic profile modified to represent the glacier sole; basal ice was assumed to bridge certain bedrock concavities where striations were locally absent along the measured traverses. On the basis of observations of subglacial cavities (Vivian 1975), a simple curvilinear form was assumed for the glacier sole where the ice had evidently been detached from the glacier bed. Inasmuch as cavitation not only modifies the effective roughness of the glacier sole, but also reduces the resistive drag because part of the bed no longer contributes to the total basal drag, the effective drag computed from the spectral analyses of the inferred glacier sole was reduced by a factor proportional to the relative length of the profile along which the ice was apparently not in contact with the bed. This modified basal drag led to a new sliding velocity value of about 1 m/year, still much lower than that expected from the surface velocity measurements.

The discrepancy between calculated and expected sliding values may be largely due to the form of the bed profile; the bed was relatively rough and contained many sharp corners that not only introduce many high frequency roughness elements, but also violate the assumption of low slopes inherent in the sliding theories. Alternatively, and more importantly, the discrepancy may reflect an inadequacy of the theories, such as the one pointed out by Nye (1973b), who strongly emphasized the serious need for any data corroborative of the theories.

CONCLUSION

The principal result of our research is that, although largely unrecognized in the past, chemical processes are clearly active at the base of temperate glaciers. We have shown that these processes are significant geomorphologically because in certain carbonate terranes they appear to surpass other glacial processes in modifying the glacier bed. From a glaciological viewpoint, these chemical processes have also been shown to be significant because they could potentially influence the behavior of entire temperate glaciers by impeding glacier sliding (Hallet 1976b).

Our field studies have also brought us a better understanding of the geometry of basal ice flow over rough three-dimensional rock surfaces, which is of particular interest because it can be compared and contrasted with the assumptions and predictions of the recently developed glacier sliding theories.

Lastly, our quantitative data on the roughness of the former glacier bed of the Grinnell Glacier provide one of the first roughness measurements necessary to establish whether or not the sliding theory adequately predicts the resistive basal drag on a temperate glacier.

LITERATURE CITED

BOULTON, G.S., 1974. Processes and patterns of glacial erosion. *In:* Glacial Geomorphology, edited by Coates, D.R., Binghamton, New York, State University of New York, 41-87.

DEMOREST, M., 1938. Ice flowage as revealed by glacial striae. Jour. Geology, v. 46, 700-725.

HALLET, B., 1976a. Deposits formed by subglacial precipitation of $CaCO_3$. Geological Society of America Bulletin, v. 87, 1003-1015.

HALLET, B., 1976b. The effect of subglacial chemical processes on glacier sliding. Jour. Glaciology, v. 17, 209-221.

HALLET, B., 1976c. Implications of spectral analyses of glacier beds on the sliding of glaciers. EOS Transactions - American Geophysical Union, v. 57, p. 325.

KAMB, B., 1970. Sliding motion of glaciers: Theory and observation. Rev. Geophysics and Space Physics, v. 8, 673-728.

KAMB, B., 1972. Experimental recrystallization of ice under stress: *In:* Flow and fracture of rocks (Griggs Volume), edited by Heard, H.C., Borg, I.Y., Carter, N.L., and Raleigh, C.B., Washington, D.C., American Geophysical Union, 211-241.

MORLAND, L.W. and BOULTON, G.C., 1975. Stress in an elastic hump: The effects of glacier flow over elastic bedrock. Proceedings of the Royal Society of London, Ser. A, v. 344, 157-173.

NYE, J.F., 1969. A calculation on the sliding of ice over a wavy surface using a Newtonian viscous approximation. Proceedings of the Royal Society of London, Ser. A, v. 311, 445-467.

NYE, J.F., 1973a. Water at the bed of a glacier. IUGG/IASH/Commission of Snow and Ice, Symposium on the Hydrology of Glaciers, Cambridge, England, 1969. IASH Publ. no. 95, 189-194.

NYE, J.F., 1973b. The motion of ice past obstacles. *In:* Physics and chemistry of ice, edited by Walley, E., Jones, S.J., and Gold, L.W., Symposium on the Physics and Chemistry of Ice, Proc., Ottawa, Canada, 1972. Ottawa, Royal Soc. Canada, 387-394.

NYE, J.F., 1976. Water flow in glaciers: Jokulhlaups, tunnels and veins. Jour. Glaciology, v. 17, 181-207.

SHREVE, R.L., 1972. Movement of water in glaciers. Jour. Glaciology, v. 11, 205-214.

VIVIAN, R.A., 1975. Les glaciers des Alpes Occidentales. Grenoble, Imprimerie Allier, 513 p.

WEERTMAN, J., 1972. General theory of water flow at the base of a glacier or ice sheet. Reviews of Geophysics and Space Physics, v. 10, 287-333.

WEISS, R.F., and FLORSHEIM, B.H., 1965. Flow in a cavity at low Reynolds numbers. Physics of Fluid, v. 8, 1631-1635.

OBSERVATIONS OF GLACIER VARIATIONS IN GLACIER BAY NATIONAL MONUMENT

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INTRODUCTION

One of the principal purposes in establishing Glacier Bay National Monument was to enhance the study of its glaciers and related phenomena. The proclamation establishing the southeastern Alaskan Monument signed by President Coolidge on 26 February 1925, stated: "This area presents a unique opportunity for the scientific study of glacial behavior and of resulting movements and development of flora and fauna and of certain valuable relics of ancient interglacial forests. . . . The area is also of historic interest having been visited by explorers and scientists since the early voyages of Vancouver in 1794, who have left valuable records of such visits and explorations." (Quoted in Cooper 1956:18)

The glaciers of the Monument are of varying sizes and characteristics. Thirteen are over 20 km in length, seven are over 30 km and three over 40 km. Eleven exceed an area of 100 km^2 and three reach 300 km^2 or more. Most spectacular are the eleven large glaciers which discharge icebergs directly into tidewater. No less interesting or significant from the scientific point of view, are the valley glaciers, now numbering at least 13, which terminate on land or the innumerable small hanging glaciers which occur in almost every valley.

Glacier Bay National Monument comprises a number of drainage basins besides Glacier Bay itself. These are Taylor Bay to the west, also opening into Icy Strait, and several inlets and drainage basins, including Lituya Bay, whose glaciers drain from the Fairweather Range into the Gulf of Alaska. (Boehm 1975:36-45)

In 1926, I was able to visit most of the glaciers in the Monument. A number of interesting changes were found which had not previously been reported, such as a substantial recession of the Muir, Johns Hopkins, and Hugh Miller glaciers (Field 1926). With the strong encouragement of prominent glacial geologists including H. F. Reid, C. W. Wright, and Lawrence Martin, who had conducted pioneering research in the Bay area, a long-term project was devised to record glacier variations by means of photography and surveys at intervals of a few years. My first serious effort in this regard was made in 1935 with William S. Cooper, who had begun his observations in 1916. Other companions over the years have included D. B. Lawrence (1958), M. M. Miller (1964, 1970), R. P. Goldthwait (1963, 1966), Dave Bohn (1967), G. M. Haselton (1966), and Austin Post.

My involvement in this program, which carried forward the observations begun by Reid in 1890, has thus spanned 50 years and has included 13 separate visits, the most recent in 1976. Since 1940, the project has been carried out under the auspices of the American Geographical Society, whose encouragement and support have made this continuity possible.

The year 1958 proved to be a turning point in these efforts when the investigation became part of the International Geophysical Year program. By then the National Park Service had established a headquarters in Bartlett Cove with a well-equipped vessel for operations in the Bay, and was in a position to provide logistical support. This valuable assistance and the enthusiastic cooperation of the Park Service personnel over the last 18 years has been of great help and is gratefully acknowledged.

Many researchers in various disciplines have increased our knowledge of the historical and current fluctuations of the glaciers. A number of them have contributed to the photographic record, which today includes a magnificent collection of aerial pictures taken since 1929. The most recent are those produced by Austin Post of the U. S. Geological Survey (Post and LaChapelle 1971).

Scientific research in the Monument has greatly benefited from the availability of unusually good map coverage over a period of eight decades. The first topographic surveys were carried out in the 1890's by Reid (1892, 1896). Then, because the boundary between Alaska and British Columbia crosses the upper drainage basin of Glacier Bay, additional mapping was done by the International Boundary Commission in 1894 and again from 1907 to 1912. The newest topographic maps, based on an aerial survey by the U. S. Navy in 1948, were issued by the U. S. Geological Survey in the 1950's and 1960's. More recent data on the positions of some of the glacier termini have been added in later editions.[2]

GLACIER FLUCTUATIONS

One of the most interesting aspects of glacier research in the Monument and its surroundings is the varied behavior of the glaciers over the last two centuries and particularly in the last eight decades. Since the 1890's these changes have been well documented. "Nowhere in Alaska, perhaps nowhere in the world," wrote Cooper (1937:1), "has there occurred within recent years so rapid a disappearance of glacial ice. . . . And yet the fundamental problems, the suddenness of rise and decline and their apparently local character, still await solution." Another chapter has since been added, for several glaciers in the Monument have been actively advancing or have remained relatively stable during the last four decades.[3] Such anomalous behavior is not unique to this area, having also occurred elsewhere along Alaska's southern coast. The primary purpose of this paper is to review this fascinating situation and to examine some of the hypotheses which seem to

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[2]Current maps showing the glaciers of Glacier Bay National Monument include: USGS Alaska Topographic Series 1:250,000 sheets for Juneau, Mt. Fairweather, and Skagway, and the corresponding sheets of the 1:63,360 Series (Topographic); a map issued by the National Park Service in a folder primarily for tourists, entitled "Glacier Bay," which shows the glaciers and inlets as of the mid-1970's; and other maps appearing in recent reports cited in the text.

[3]The terms advance and recession refer to the position of the terminus, not to the flow of ice which, even in receding glaciers is toward the terminus.

offer possible explanations.

Vancouver's expedition in 1794 found the lower end of the Bay blocked by a huge glacier, which we now know originated over 130 km away on the slopes of the Fairweather Range. In places it was 20 km wide and over 1200 m thick. Since then this glacier has largely disappeared and its remnants are the independent glaciers which now terminate at the heads of the various inlets. As a result of this recession, Glacier Bay has been enlarged from less than 10 km in length, to a body of water extending slightly over 100 km to the head of northwestern arm in Tarr and Johns Hopkins inlets and some 86 km northward to the head of Muir Inlet. The water area of the Bay, with depths up to 300 m, has been enlarged by about 1330 km^2 which, for comparison, is approximately the present area of all the glaciers in the Swiss Alps. However, the total area of ice removed is almost twice as great. Bengtson (1962:1) estimated it to be around 2600 km^2 with a thickness ranging up to 1100 m.

In Muir Inlet alone, recession has totaled 36 km over the past 84 years, representing an average annual rate of 428 m. And from the contours on Reid's map (1896:Pl. LXXXVI), it can be determined that at the position of the 1976 terminus the ice surface was then at an altitude of about 870 m. Adding the now known depth of the inlet of around 230 m, the total thickness of ice that has been lost at this point in eight decades is at least 1100 m.

While Muir Glacier has continued to recede at an average annual rate of over 400 m, the trunk glaciers of the northwestern arm of Glacier Bay have had a very different recent history. Muir's Pacific Glacier of 1879, receding at approximately the same rate as the Muir, became two separate glaciers in the 1880's, the Grand Pacific in Tarr Inlet and the Johns Hopkins in the inlet of that name. The Grand Pacific reached its most recessed position near the head of the fiord in the 1925-1935 period and has since readvanced 2.3 km, while the Johns Hopkins reached the head of its fiord around 1930 and has since readvanced about 1.8 km.

In the other inlets and valleys which formerly had tributaries of the main trunk glacier of the Bay, the fluctuations of the last century have also been highly varied. Carroll and Rendu glaciers had stopped receding by the 1890's when they were still tidal, and their termini, now on land, have not appreciably changed position since then. Margerie Glacier, a tributary of the Grand Pacific up to about 1911, has not changed and remains tidal. Lamplugh Glacier, formerly a tributary of the Johns Hopkins, also remains tidal near the entrance of its fiord and close to its position in the 1890's, while Reid Glacier, following a recession of 2.5 KM from 1926 to 1941, also remains tidal near the head of its inlet.

In the southwestern part of the Bay, three glaciers which were formerly tidal--the Hugh Miller, Charpentier, and Geikie--have receded to land during the first half of this century. The Hugh Miller and Geikie are now 2 km and 3.6 km, respectively, from tidewater and have been receding at an average annual rate of about 60 m.

These exceptional fluctuations in Glacier Bay itself are even more noteworthy if we examine the other glaciers in the western part of the Monument (draining into Taylor Bay, Lituya Bay, and the Gulf of Alaska) as well as those outside the Monument, flowing from common divides and snowfields north into the Alsek, Tatshenshini, Tsirku, and Takhin rivers, and eastward into Lynn Canal (Field 1975:152-157, 183-204).

While there have been some instances of substantial retreat outside of Glacier Bay itself, several of the glaciers, such as the La Perouse, are still within a few hundred meters of old forest, and there are also several glaciers which are today more advanced than in the nineteenth century. Brady Glacier, in the basin immediately west of lower Glacier Bay, is reported to have advanced eight km between Vancouver's visit in 1794 and that of the Boundary Survey in 1894 (Klotz 1899:528), and was found by Bengtson in 1960 still to be advancing slowly (1962:82). In the vicinity of Lituya Bay, South Crillon Glacier has been advancing into Crillon Lake in recent decades, and North Crillon and Lituya glaciers are now five to six km more advanced than when mapped by La Perouse in 1786 (Klotz 1899:526; Goldthwait et al. 1963:63-68).

In the valleys north of Glacier Bay, Tsirku Glacier is more advanced than in 1910 and Bertha Glacier has withdrawn only a few hundred meters from a maximum established in the early 1880's. Other glaciers in the Tsirku and Takhin valleys have also changed little in recent decades. These are of special interest because they drain from the same ridges as the glaciers of Muir Inlet to the south, where such great recession has taken place in the last two centuries. Similarly, to the east, Davidson Glacier of Lynn Canal, which flows from the same accumulation area as the Casement of Muir Inlet, is still within 2.5 km of its maximum position of recent centuries.

Thus there are glaciers within a radius of 120 km in the Monument, and just outside it, which have behaved in completely disparate ways during the last one to two centuries, and even in the last few decades. Clearly, other factors are required to explain these changes than meteorological conditions affecting rates of snow accumulation and melting, and in turn causing variations in the altitude of the snowline and the level of maximum snowfall.

In general, the glaciers that end on land have behaved in a fairly consistent manner. A few glaciers have fluctuated, or surged, within relatively defined limits, while most glaciers have receded in what can be considered a normal response to the meteorological conditions which have prevailed over the past century. So far as is known, no glacier ending on land has advanced beyond limits attained during the nineteenth century.

In contrast, the behavior of glaciers discharging directly into tidewater has been erratic, confounding explanations which assume a regional pattern of climatic change. The particular characteristics of these glaciers therefore need to be examined in order to explain events of the last two centuries in the Glacier Bay area.

FLUCTUATIONS OF TIDAL GLACIERS

Tidal glaciers have long been regarded by most observers as exceptions to the general notion of glaciers as recorders, veritable archives in fact, of climatic change. Post (1975) wrote of their ". . . asynchronous advances and retreats which are not directly related to climate." The explanation for this, which is emerging from empirical observations over the past half century, is based on a number of separate considerations which have been noted by various observers, and which now may be combined to furnish what may lead to more satisfactory answers.

The whole regime of tidal glaciers is very different from land-ending glaciers. These differences appear quite adequate to account for

rapid, even catastrophic recession, as well as for advances during periods of general, widespread recession. Climate cannot be neglected entirely, for it is still an important controlling factor in any change in the rates of snow accumulation and wastage. But local factors are also important. Glaciers which have the necessary volume of ice flow to reach sea level have generally been nourished from higher elevations than other glaciers. Since these high basins may be less affected by a change in the altitude of the snowline, the tidal glaciers may respond in a different way than the glaciers originating at lower altitudes. For instance, Mercer (1961) pointed out that shifts in the snowline could provide an important triggering mechanism affecting the fluctuations of tidal glaciers. Yet despite the importance of these meteorological factors, there are others which, at least on a short-term basis, appear to exert a more direct influence on the behavior of tidal glaciers.

The characteristics peculiar to tidal glaciers include the processes that govern terminal ablation in tidewater and the mode of flow below the snowline.

Many observes beginning with Reid in the 1890's have remarked on the high rate of wastage at a tidal terminus due to calving as well as the melting action of tidewater (Post and LaChepelle 1971: 77). It has also been observed that the rate of recession is influenced by ". . . the extent of the terminal ice exposed to tidewater as determined by the depth of the inlet and the length of the tidal ice cliff . . ." (Field 1947:391). Goldthwait (1963:46) carried this an important step further by observing that the rate of recession has ". . . little to do with the feeding of the ice, but is controlled entirely by the forms and rates of ablation." He added: "The most notable deposit of recession is the outwash delta" and, at a retreating terminus in deep water, ". . .deposits never have time to build up to the surface before the ice has retreated far up the fjord; but where the retreat is slow and the fjord is shallow, a substantial broad outwash has developed." Post (1975) made an important point noting that ". . . instability results when a tidal glacier retreats even a short distance into a deep basin from a stable position on a terminal shoal. The glacier may then retreat many kilometres per year as innumerable icebergs, some of immense size, break away from the glacier." Bengtson (1962:85) in his studies at Brady Glacier also recognized the importance of the deposition of outwash in front of the terminus as being ". . . probably primarily responsible for the Brady maintaining itself while other glaciers in Glacier Bay, also originating in high neve fields, have retreated drastically since the Little Ice Age maximum in 1850."

During the period of recession all outwash and moraine are deposited in deep water and are spread out over the floor of the inlet. When the terminus stops receding, however, all this material accumulates at the base of the ice cliff and begins to form a barrier protecting the terminus from tidewater. This reduces both the rate of calving and the area exposed to melting. As deposition continues in front of the terminus, further reduction in the rate of terminal ablation may result in the initiation of an advance. As this advance proceeds, the moraine-outwash barrier is pushed ahead until equilibrium is established once more between the down-valley flow of ice and melting at the terminus. When the advance ceases, further deposition increases the insulation of the terminus from tidewater and its melting effect may then be cut off entirely. Since this is the result of sedimentation, it can occur without a change in climate or a change to a positive mass balance in the glacier.

Another characteristic of tidal glaciers which profoundly affects their regime is their mode of flow. In land-ending valley glaciers, the rate of flow tends to decrease gradually from the snowline to the terminus (Meier 1960:21; Sharp 1960: 42). In a tidal glacier, however, the rate of flow is maintained down to the ice cliff and may even increase in the lower part of the glacier (Ahlmann 1953:8). These differences in land-ending and tidal glaciers are basic to an understanding of the differences in the behavior of the two types of glaciers. In a tidal glacier, there is little frontal resistance, which permits a relatively high rate of flow right to the terminus. If the terminus is receding and the flow of ice is greater than can be supplied from the area of accumulation, the glacier will gradually be depleted and its surface level will be lowered. This will occur at a greater rate than if subject to surface ablation (Field 1947:394). With the lowering of the ice surface, the snowline on the glacier will migrate toward the source area, further reducing the area of accumulation and the nourishment of the glacier. The reduction in volume of the glacier therefore becomes cumulative and proceeds as a function of the mechanics of ice flow and largely independent of climatic factors.

The difference in the rate of flow in tidal and land-ending glaciers is indicated by a few measurements. Reid in 1890 (1892:44) recorded a daily flow rate of 2.2 m in the lower course of Muir Glacier, a figure which is consistent with more recent measurements of 1.8 to 2.2 m at two tidal glaciers in Prince William Sound (Post 1967:D36; Field 1975:v. 2:372, 389). However, in exceptional cases the velocity can be as much as 20 m per day as reported by Plafker and Miller (1958) at Guyot Glacier. In contrast, a typical measurement at Casement Glacier in Muir Inlet, at a point 2.7 km above its land terminus, was 0.23 m per day (Peterson 1970:124-126). Thus the velocity of a tidal terminus may be nine to nearly a hundred times as great as a glacier ending on land. Such variations in flow patterns, which affect the whole lower end of a glacier, must be taken into account when a terminus passes through the various stages between tidal and non-tidal status.

From these basic differences in the rates of terminal ablation and rates of flow, it can be seen how, when land-ending glaciers are generally receding, some tidal glaciers may recede at far greater rates, while others may be advancing slowly in neighboring inlets. Apparently, no significant regional climatic change is required to produce these startling changes in the glacier cover.

Another result of the catastrophic recession of tidal glaciers in Glacier Bay (and elsewhere) is the accompanying vast reduction of the ice-covered area, which amounts to virtual deglaciation. This in itself should cause profound changes in the heat exchanges in the area. With the reduced reflectivity or albedo, more heat is absorbed by the exposed terrain and open water. This should lead to a modification of the local climate and a rise of the snowline in the immediate vicinity, which in turn would lead to an increase in the rate of glacier recession. Such a change would be local rather than regional, and thus would affect a recently deglaciated area such as Glacier Bay, but not the adjacent drainage basins.

APPLICATION OF CONCEPT

The above discussion suggests some interpretations of the anomalous behavior of the glaciers in Glacier Bay National Monument and its vicinity. These findings are offered tentatively with the hope that others will undertake further research to test their validity.

In the middle of the eighteenth century, the main glacier of Glacier Bay had advanced to the opening into Icy Strait during a long period when meteorological conditions favored the expansion of glaciers. By 1794, the glacier had already receded a few kilometers from its maximum, but still terminated in relatively shallow water near the north end of Bartlett Cove. In the less favorable climate for glaciers during the nineteenth century, the retreat continued up Glacier Bay and became much more rapid when water of 180 to 500 m depth was reached north of Willoughby Island.

The recession in the northwest arm was in deep water all the way to the heads of Tarr and Johns Hopkins inlets. Records show no prolonged pauses in this retreat. In Muir Inlet, however, rapid recession was interrupted at three points where the inlet is relatively narrow and shallow: northwest of Mt. Wright in the 1890's; southwest of The Nunatak from 1926 to 1931, and south of Riggs Glacier from 1946 to 1952. At these three places in the inlet, the ice front stood in water with a depth of less than 183 m (100 fathoms) so that the surface of the ice front in contact with tidewater was greatly reduced. In contrast, when the terminus was in the wider and deeper basins between these narrows, the rates of annual recession increased. As an example, from 1906 to 1907, when the terminus was in water over 300 m deep, recession was reported to be 3.9 km.

The glaciers in Muir Inlet offer a further illustration of the contrast in terminal ablation between tidal glaciers in deep water and those on land or in shallow water. Muir, McBride, and Riggs glaciers all drain from adjacent snowfields of comparable size and elevations, so that there is no good reason to believe that there has been any unusual change in the rates of snow accumulation or wastage at any one of the glaciers.

McBride Glacier became independent of the Muir about 1945 and has since receded less than a kilometer, forming an outwash plain across the valley mouth and, thus further protecting the terminus. Riggs Glacier became independent in 1961 and, although the glacier seems to be slowly shrinking in volume, its terminus remains in about the same position. Soundings within 200 m of the ice cliff suggest relatively shoal water of less than 35 m. In complete contrast, during this same time, the Muir retreated up the deep inlet at average annual rates of over 400 m per year. The great depth of water at the terminus and the accompanying flow characteristics appear to be the controlling factors distinguishing the behavior of the Muir from that of its former tributaries.

In the late eighteenth century, concurrent with the beginning of the great recession in Glacier Bay, the Brady, North Crillon, and Lituya glaciers were occupying recessed positions at the heads of their deep water fiords. Deposits had presumably been forming in front of their tidal termini and, when sufficient protection was afforded by these sediment barriers, each glacier began to advance. At Brady Glacier, as Bengston points out (1962:85), the bar had probably risen to sea level in the 1870's and tidal action diminished thereafter. This allowed the glacier to advance still further (at least until 1961) to reach a balance between its flow of ice and terminal melting. Thus, for at least eight decades, during a period generally unfavorable to glacier growth, the Brady, although shrinking slowly from a slightly negative mass balance, continued to advance as a non-tidal terminus.

In Lituya Bay, both North Crillon and Lituya glaciers advanced several kilometers during the nineteenth century and up to at least the 1960's. At North Crillon Glacier a bar began to form above tide early in the present century, and by 1961 fronted over 70 percent of the terminus (Goldthwait et al. 1963:67). On the other hand, Lituya Glacier, which advanced at an average rate of about 10 m per year from 1894 to 1958, still remains mostly in tidewater.

The more recent advances of the Grand Pacific and Johns Hopkins occurred after they had receded to the heads of their respective fiords, where a balance was reached between ice discharge and terminal wastage. After an interval of a decade or so, the balance was shifted once more as outwash and moraine were deposited at their termini. The glaciers then began to advance. The bar in front of the terminus of Grand Pacific Glacier has always been visible. At Johns Hopkins Glacier, however, the terminus remains in relatively deep water, though recent soundings indicate a depth near the ice front of 82 to 120 m where earlier charts showed 330 m.

While the change from tidal to non-tidal status at Brady Glacier took place before the period of observation, a similar modification of the terminal environment has been documented in this century at Rendu and Carroll glaciers. Each ended its recession in the 1890's while still in tidewater, after which proglacial bars formed. By the late 1920's their termini were on land and still remain close to their positions of 1892.

The rates at which proglacial bars are formed from outwash and moraine material quite naturally vary at each locality. One important source is avalanche debris. Along the lower courses of such glaciers as the Ferris, tributary of the Grand Pacific, and the Johns Hopkins, both of which were at least 700 m thicker in the last century, there are unstable and over-steepened slopes subject to massive avalanching. The debris is deposited on the glacier surface and is transported by the ice or subglacial streams to the terminus. As surface moraine it tends to protect the underlying ice from the normal rate of surface ablation, thereby reducing the rate at which the glacier would normally shrink. This can cause an advance of the terminus (Field 1964:17). Eventually all this avalanche material is deposited at the terminus and increases the rate of growth of the proglacial bar.

CONCLUSION

This paper has considered a single, but critical, aspect of the complex problems relating to glacier variations. If the characteristics of tidewater glaciers are understood, it becomes easier to understand the glaciological events of the past two centuries in Glacier Bay National Monument. These interpretations can also be applied to the processes affecting all tidal glacier activities in Alaska and other parts of the world and, in all probability, they may also be relevant to the study of the waxing and waning of ice sheets terminating in sea or lake water.

The condition of the glaciers in the mid-1970's varies throughout the Monument. In Glacier Bay itself, all the glaciers in Muir, Queen, Hugh

Miller, Charpentier, and Geikie inlets are shrinking at different rates. They drain from relatively low snowfields which are being depleted by a recent substantial rise in the snowline (Goldthwait 1967:45). Although the rate of recession is fairly high at some of the glaciers, only the Muir, with its terminus in deep water, is receding at a rate which can be termed catastrophic.

In the northern and northwestern parts of the Bay, where mountains and snowfields are higher, there is no sign of massive recession at the present time. Observations of the large and small glaciers in that area indicate that relative stability has prevailed over the last half century: The main glaciers are either stable or advancing; furthermore, the small glaciers which, because of their shorter response time, are usually considered more reliable indicators of changes in local meteorological conditions, show no appreciable trend of recession. In Rendu Inlet the small glaciers visible in Reid's photographs of 1892 are almost the same size in 1976; in Tarr Inlet there has also been little change in the small glaciers since the 1920's; and in Johns Hopkins Inlet, large and small glaciers alike, although they have oscillated quite dramatically at different times, remain in 1976 very much in the same condition as in 1935. It can therefore be presumed that the local meteorological factors affecting glacier regimen in these areas of the upper Bay have remained substantially stable for several decades.

Elsewhere in the Monument, slow recession has been the trend of the glaciers which terminate on land. The glaciers that are tidal remain at or near their maximum positions of the past two centuries.

The one predictable process in Glacier Bay is the continuation of rapid sedimentation in front of the glaciers and at the heads of all the inlets, whether occupied by tidal or nontidal glaciers. As Goldthwait (1963:46) has indicated, this geological process has been important in the glacial history of this area over the past 10,000 years and in all probability will continue to have a significant influence on the future fluctuation of the glaciers.

More studies are needed of the processes that have been discussed in the foregoing pages, especially such features as the heat exchange at tidal ice fronts, and the rates of sedimentation at the heads of the inlets.

As part of a routine program it would seem desirable to continue systematic observations of fluctuations at the lower ends of the glaciers. These require relatively simple procedures that are not elaborate or expensive. However, it must be kept in mind that such observations tend to record the end results, not the causes, of highly complex processes which in many cases take place at higher elevations. To study the latter aspects of glaciology, involving ice mechanics, measurements of mass balance, and glacial-meteorological relationships, requires considerably more sophisticated techniques and more complicated logistics. Although more expensive, they are necessary to develop an adequate understanding of the relationship between glacier regimen and the climatic environment.

To a considerable extent such programs of research are in the realm of basic science and incorporate some very practical aspects which relate to the planning functions and the interpretive programs of the National Park Service. They also contribute significantly to the enjoyment and understanding of the Monument's natural history by the general public. Glacier Bay's scenic attractions are only underscored by its importance as a locale, among the best in the world, for the study of the various phenemona associated with glacier fluctuations.

LITERATURE CITED.

AHLMANN, H. WILSON 1953. Glacier Variations and Climatic Fluctuations. Bowman Memorial Lectures. Series Three. Amer. Geog. Soc.

BENGTSON, K. B. 1962. Recent History of the Brady Glacier, Glacier Bay National Monument, Alaska, U. S. A. Extract of Pub. No. 58 of the I.A.S.H. Commission of Snow and Ice, 78-87.

BOEHM, WILLIAM D. 1975. Glacier Bay: Old Ice, New Land. Alaska Geographic. vol. 3, no. 1.

BOHN, DAVE 1967. Glacier Bay: The Land and the Silence. Sierra Club, San Francisco.

COOPER, WILLIAM S. 1937. The Problem of Glacier Bay, Alaska: A Study of Glacier Variations. Geog. Rev. 27:37-62.

_____ 1956. A Contribution to the History of the Glacier Bay National Monument. Dept. of Botany, Univ. of Minnesota.

FIELD, WILLIAM O. 1926. The Fairweather Range: Mountaineering and Glacier Studies. Appalachia 16:460-472.

_____ 1947. Glacier Recession in Muir Inlet, Glacier Bay, Alaska. Geog. Rev. 37:369-399.

_____ 1964. Observations of Glacier Variations in Glacier Bay, Southeastern Alaska, 1958 and 1961, Glacier Bay National Monument. Preliminary Report. Dept. of Exploration and Field Research, Amer. Geog. Soc.

_____ Editor. 1975. Mountain Glaciers of the Northern Hemisphere. vol. 2: Cold Regions Research and Engineering Laboratory, Corps of Engineers, U. S. Army. Technical Information Analysis Center.

GOLDTHWAIT, RICHARD P. 1963. Dating the Little Ice Age in Glacier Bay, Alaska. Internat'l. Geog. Cong., XXI Session, Norden, 1960, Part XXVII:37:46.

_____ 1966. Glacial History. Part I: 1-15, in Goldthwait et al. Soil Development and Ecological Succession in a Deglaciated Area of Muir Inlet, Southeast Alaska. Inst. of Polar Studies, Rept. No. 20, The Ohio State Univ. Research Foundation.

_____ 1967. Evidence from Alaskan Glaciers of Major Climatic Changes. Royal Meteor. Soc. Proc. of the Internat'l. Sumposium on World Climate from 8000 to 0 B.C. 40-53.

GOLDTHWAIT, RICHARD P., IAN C. MCKELLAR and CASPER CRONK. 1963. Fluctuations of Crillon Glacier System, Southeast Alaska. Bull. Internat'l. Assoc. Sci. Hydrology, 8:62-74.

HASELTON, GEORGE M. 1966. Glacial Geology of Muir Inlet Southeast Alaska. Inst. of Polar Studies Rept. No. 18. The Ohio State Univ. Research Foundation.

KLOTZ, OTTO J. 1899. Notes on Glaciers of Southeastern Alaska and Adjoining Territory. Geog. Jour. 14:523-534.

LAWRENCE, DONALD B. 1958. Glaciers and Vegetation in Southern Alaska. Amer. Scientist 46:89-122.

MEIER, MARK F. 1960. Mode of Flow of Saskatchewan Glacier, Alberta, Canada. U. S. Geol. Surv. Prof. Paper 351.

MERCER, J. H. 1961. The Response of Fjord Glaciers to Changes in the Firn Limit. Journ. Glac. 3:850-858.

MILLER, MAYNARD M. 1964. Inventory of Terminal Position Changes in Alaskan Coastal Glaciers Since the 1750's. Proc. Amer. Philos. Soc. 108:257-273.

_____ 1970. 1946-1962 Survey of

the Regional Pattern of Alaskan Glacier Variations. Nat. Geog. Soc. Research Reports, 1961-1962 Projects: 167-189.
PETERSON, DONALD B. 1970. Glaciological Investigations on the Casement Glacier, Southeast Alaska. Inst. of Polar Studies, Rept. No. 36. The Ohio State Univ. Research Foundation.
PLAFKER, GEORGE and DON J. MILLER. 1958. Glacial Features and Surficial Deposits of the Malaspina District, Alaska. U. S. Geol. Surv. Invest. Map 1-271.
POST, AUSTIN 1967. Effects of the March 1964 Alaska Earthquake on Glaciers, U. S. Geol. Surv. Prof. Paper 544-D.
_____1975. Preliminary Hydrography and Historic Terminal Changes of Columbia Glacier, Alaska. Hydrologic Invest. Atlas, U. S. Geol. Surv.
POST, AUSTIN and EDWARD R. LACHAPELLE. 1971. Glacier Ice. The Mountaineers, Seattle; Univ. of Washington Press, Seattle and London.
REID, HARRY FIELDING. 1892. Studies of Muir Glacier, Alaska. Nat. Geog. Mag. 4:19-84.
_____ 1896. Glacier Bay and Its Glaciers. U. S. Geol. Surv. Part I: 421-461. Extract from the 16th Ann. Rept. of the Survey, 1894-95.
SHARP, ROBERT P. 1960. Glaciers. Condon Lectures, Oregon State System of Higher Education, Eugene.

GLACIER FLUCTUATIONS IN GLACIER BAY, ALASKA, IN THE PAST 11,000 YEARS

Garry D. McKenzie[1]

INTRODUCTION

Glacier Bay occupies the central and eastern portions of Glacier Bay National Monument. The Monument, created in 1925, is situated in southeastern Alaska about 60 km northwest of Juneau and has been of scientific and popular interest for almost a century. Detailed research on glacier variations began in 1890 (Reid 1892, 1896) and ecological studies followed (Cooper 1931; and others). Many people visited the area by excursion steamer and interest was heightened through descriptions similar to those of Hallock (1886:176):

> The Muir is the ultimate objective point of sightseers, who, by the time they have become accustomed to the unfamiliar blending of Mediterranean with Alpine scenery so exclusively characteristic of the North Pacific coast, are partially prepared for the astounding revelation which presently awaits them at the head of the Glacier Bay....But what shall compare with the Muir glacier when the moonlight is upon it, and all the phosphorescence of the Pacific Ocean beats in billows of liquid flame against its toppling, crumbling walls? When lunar rainbows are tossed in air against the mounting columns of foam that are shivered into spray by the plunging mountains of ice?

Glacier Bay is a fiord, over 100 km long and 20 km wide, which, with arms and tributaries makes up about 14 percent of the Monument (Figure 1). It is surrounded by lowlands of bedrock hills (about 300 m high) and unconsolidated materials. Mountains adjacent to the lowlands are 1200 to 2200 m high in the east and in the west are usually between 2400 and 3600 m with one peak reaching 4670 m.

Retreat from the Neoglacial maximum in Glacier Bay has been over 100 km at an average rate of about 400 m a^{-1}. Retreat continues in the Muir system of Glacier Bay and has been well-documented by maps and photographs since 1890 (Reid 1896; Field 1947). Fluctuations of glacier termini in Glacier Bay prior to the observed retreat are interpreted from the glacial stratigraphy and by analogy with historical variations. Most of the details of these fluctuations come from studies in Adams Inlet (McKenzie 1970; McKenzie and Goldthwait 1971) and in Muir Inlet (Haselton 1966; Goldthwait 1963, 1966). Although the history of fluctuations of glaciers in Glacier Bay is rather simple, it is also incomplete, particularly because of the absence of detailed information from the western side of Glacier Bay.

This history can be summarized as follows. A Late Wisconsin retreat of ice from the Pacific Ocean was followed by marine invasion, reaching, in the eastern portion of Glacier Bay, 75 km from Icy Strait by 11,000 B.P. (Figure 1). Glaciers probably continued to shrink to minimal positions during the Hypsithermal (7000 to 4000 B.P.) with an Early Neoglacial advance about 2700 B.P. in the Muir system, but probably as early as 4700 B.P. in the Russell system in the western part of Glacier Bay. Although fluctuations in these glacier systems undoubtedly occurred during the Early Neoglacial, no record of such fluctuations or terminal positions has been found in the Bay, although they exist in the Brady system (Derksen 1976). About 800 B.P. a retreat (Little Optimum of Lamb and others, 1966) of the Muir system occurred and was recorded in the eastern portion in Adams Inlet. Late Neoglacial advance followed this retreat filling Glacier Bay with ice as far as Icy Strait, where it remained until about A.D. 1750.

RETREAT OF WISCONSIN ICE

During the Wisconsin maximum, the upper portion of Glacier Bay was filled with glacier ice to a thickness of more than 1200 m (Coulter et al. 1965), with surrounding higher peaks in the vicinity existing as unglaciated nunataks. Ice extended from Glacier Bay down Icy Strait and Cross Sound to the Pacific Ocean. Most of the lowland areas in the southwestern corner of the Monument were covered with ice which extended onto the continental shelf during a lowered sea-level. Not all coastal areas in the western portion of the Monument were ice-covered; north of Icy Point only parts of the coastal region were penetrated by glaciers from the Fairweather Range (Coulter et al. 1976; Goldthwait et al. 1963; Derksen 1974, 1976). The probable terminal position of the Late Wisconsin ice about 15,000 B.P. is given in Figure 1.

The probable positions of ice about 11,000 B.P. are similar to ice positions within the last 25 years in Glacier Bay. Retreat of the Wisconsin ice from the coastal region could have occurred in several hundred years in a fashion similar to, but slower than, the Little Ice Age retreat. Evidence for the retreat in Glacier Bay is the glaciomarine deposits with shells, for example, the Forest Creek Formation which is as much as 60 m above present sea level in the Muir Inlet-Adams Inlet area (Figure 1). These deposits rest on Wisconsin till and are radiocarbon-dated at 10,940 ± 155 yrs B.P. (I-2395) and 11,170 ± 225 yrs B.P. (I-2396). Similar deposits recording marine invasion over a depressed land are found east of Gustavus (D.A. Brew pers. comm.) and west of Taylor Bay (Derksen 1976).

HYPSITHERMAL

A possible post-Wisconsin readvance of ice in the upper portion of Glacier Bay has been suggested on the basis of a diamicton overlying the Forest Creek Fm in Muir Inlet (Haselton 1966); however, the evidence for this is incomplete (McKenzie and Goldthwait 1971). Retreat of glaciers in the Monument probably continued for several millenia, reaching minimal terminal positions between 7000 and 4000 B.P., the Hypsithermal maximum, when temperatures were probably slightly warmer than now (Goldthwait 1966). About 6000 B.P., terminal positions of the glaciers in the area were probably back of their present positions (Figure 1). No direct evidence for this is available. In the eastern part of Glacier Bay the glaciers and stagnant ice masses

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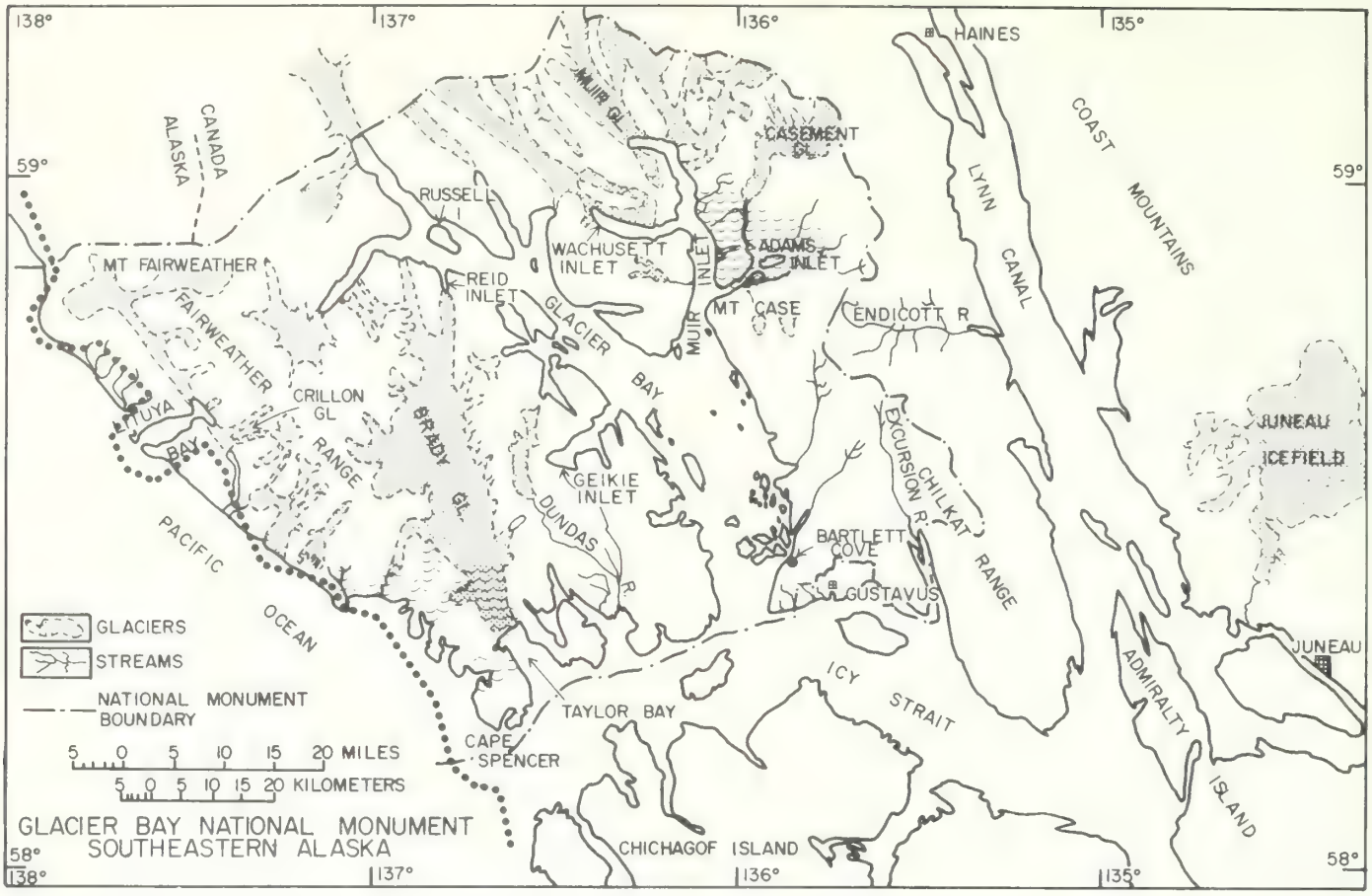

FIGURE 1. Probably terminal position of the Lake Wisconsin ice (15,000 B.P.) is indicated by dotted line; uplifted areas with evidence of marine inundation (11,000 B.P.) are indicated by regions of wavy lines. See text for data sources for this and other figures.

are expected to continue receding because of the relatively high firn limit of 1200 m (Peterson 1970). The behavior of glaciers in the western portion of Glacier Bay might not have followed this trend since some of them ended their Little Ice Age retreat several decades ago.

During the Hypsithermal outwash gravels continued to be deposited in the fiords and surrounding inlets and valleys of Glacier Bay. In the Muir Inlet area these gravels reached present sealevel about 7000 B.P. (Goldthwait 1963) and continued to build, reaching 41 m by 1765 B.P. (Y-304), in the southern part of the Inlet. Similar infilling of Adams Inlet to the west was delayed, possibly because of fewer and smaller glaciers as outwash sources, until about 3850 B.P. (I-3068). This infilling lasted until about 1700 B.P. when a lake formed in Adams Inlet, probably due to outwash damming of the entrance to the Inlet.

EARLY NEOGLACIAL

After the Hypsithermal maximum, the Russell Glacier system (Ovenshine 1967) began to expand in upper Glacier Bay. Till deposted over wood (4680 B.P., Y-9) in Reid Inlet supports this idea; however, the extent of this advance is unknown. To the east in the Muir Glacier system, the first record of advancing ice is later in the Early Neoglacial: 2735 B.P. (I-69-15) in Wachusett Inlet, and 2120 B.P. (I-1610) and 1975 B.P. (I-58-11) in Muir Inlet. By 1500 B.P. the ice probably was well down Glacier Bay, possibly as far as Drake Island (Figure 2). The 1540 B.P. (Y-4) date on wood in till on the south side of Geikie Inlet and the existence of an ice-dammed lake in Adams Inlet (McKenzie 1970) support this interpretation. The actual positions of the ice in Glacier Bay are unknown and only inferred from the events in the Muir system and Geikie Inlet. A detailed interpretation of the stratigraphy in the Geikie region is required to test this hypothesis. Depending upon the degree of fiord filling by outwash at this time, there might have been many advances and retreats of the Russell system in Glacier Bay during the Early Neoglacial for which evidence has not yet been found in the Bay or its tributaries.

Between 1500 and 800 B.P. ice from the Muir system, dammed by the Russell system in Glacier Bay, continued to flow eastward into Adams Inlet. Support for this is found in the eastward-sloping marginal channels on the north side of Mt. Case and in the ice-shove features in till of this age in valleys south of Adams Inlet.

LITTLE OPTIMUM

About 850 B.P. (A.D. 1100) retreat of the ice in Adams Inlet from tributary valleys to the south and east occurred and thick outwash deposits were formed. Presumably this retreat was accompanied by a thinning and retreat of the Russell Glacier in Glacier Bay; however, the position of maximum retreat is unknown, and in Figure 2 it is included only to show that it occurred.

A similar history of early Neoglacial advance,

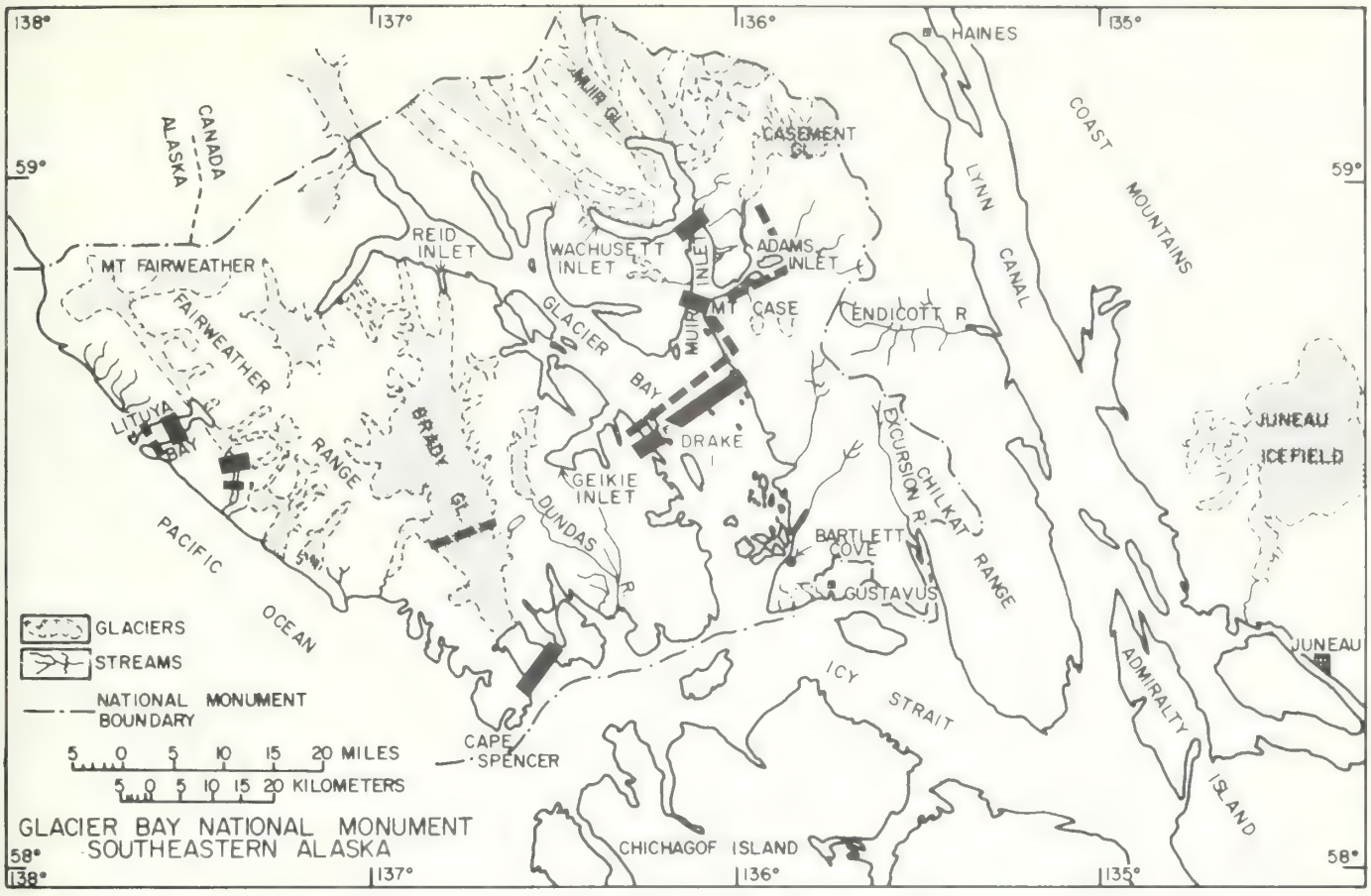

FIGURE 2. Approximate glacier positions about 1500 B.P. during the Early Neoglacial (solid line) and about 850 B.P. during the Little Optimum (broken line).

with dates of 2870 B.P. (DIC-460), 1960 B.P. (DIC-458), and 1230 B.P. (DIC-459) followed by a Little Optimum retreat has been obtained for the Brady Glacier area (Derksen 1976).

LATE NEOGLACIAL

Following the Little Optimum retreat of unknown spatial and temporal extent in Glacier Bay, the Late Neoglacial (Little Ice Age) advance occurred. This advance might have begun about A.D. 1400, reaching a maximum position at the south end of the Bay by about 1700. It probably remained there until 1750, but by 1794 when Vancouver (1798) visited the area, a bay 8-12 km deep had formed. The 6-7 m of uplift that occurred since Vancouver's mapping has probably produced the lowland areas on both sides of the entrance to Glacier Bay. This helps to account for the relatively wide bay that is shown on Vancouver's map. The maximum extent of the eastern outlet of the Glacier Bay system was at Endicott Gap near the source of Endicott River, where ice remained until about 1835.

West of Glacier Bay at Brady Glacier, maximum advance occurred about A.D. 1650, although the ice remains near that position today protected from calving by outwash (Derksen 1976). In the Lituya Bay area, Goldthwait et al. (1963) determined that the North Crillon Glacier reached the maximum Neoglacial position by about 1100 B.P. and was probably still there until 400-600 B.P. when the South Crillon Glacier was reaching its maximum Neoglacial extent. By 1786 when LaPerouse mapped the area (Klotz 1899) it was at its most distant position from the Pacific Ocean in historical time.

In Figure 3, positions of glacier termini are given for 250 B.P. (A.D. 1700) and 60 B.P. (A.D. 1890). The older positions are inferred by extrapolation from later historical observations and earlier stratigraphic data; the later positions are from the maps of Reid (1896) and the Alaskan Boundary Tribunal (1904). In the Russell system, the recession ended about 1929 when Johns Hopkins Glacier began to advance and smaller glaciers around Johns Hopkins Inlet approached equilibrium conditions (Field 1975). The Muir system continues to retreat (W.O. Field, pers. comm.), and the numerous glaciers and glacier remnants between Muir Inlet and upper Glacier Bay are expected to continue thinning since they are below the firn limit.

SUMMARY AND CONCLUSIONS

Details of Glacier Fluctuations in Glacier Bay are recorded in tributary fiords and valleys and summarized in Figure 4. Stratigraphic studies in Muir Inlet and Adams Inlet reveal a post-Wisconsin retreat at least 75 km from the entrance to Glacier Bay by about 11,000 B.P., followed by infilling of valleys and fiords with outwash gravels. This warm period, the Hypsithermal was followed by the Early Neoglacial which began about 2700 B.P. in the Muir system and about 4700 B.P. in the Russell system to the west. The Early Neoglacial was terminated by a brief retreat about 800 B.P. during the Little Optimum, according to outwash deposits in Adams Inlet. The Late Neoglacial or Little Ice Age advance reached its maximum position about 250 years ago in Glacier

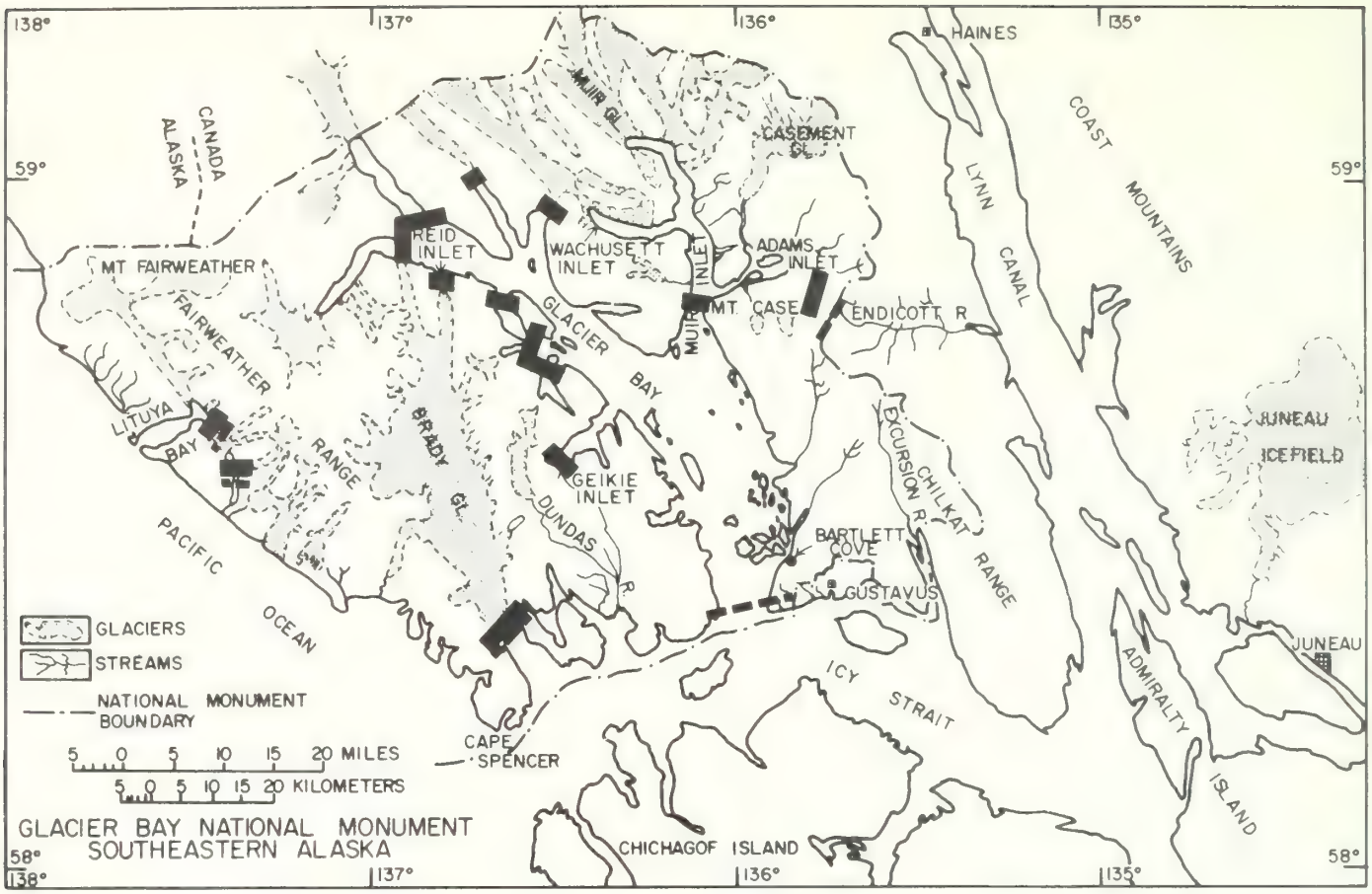

FIGURE 3. Glacier positions about 250 B.P. (A.D. 1700), during the height of the Late Neoglacial, are indicated by dashed lines; glacial positions 60 B.P. (A.D. 1890) are indicated by solid lines.

Bay, following maximum advances to the west by 50 to 850 years. Because of higher mountains and higher accumulation zones to the west, these results are not unexpected.

Future research should include a reconstruction of the topography and geography over the last 15,000 years in the Glacier Bay region using data on glacier fluctuations, and the rates of till deposition, outwash buildup, and glacier ablation which have been developed for the region (Goldthwait 1974). To meet this objective, additional field data are needed from the west side of Glacier Bay which is now a blank region with regard to the glacial stratigraphy. This paleotopographic and paleogeographic reconstruction in Glacier Bay would help in the evaluation of glacier fluctuations and their causes, and would aid in understanding future fluctuations in this well-studied and responsive glacier system.

LITERATURE CITED

ALASKAN BOUNDARY TRIBUNAL. 1904. Atlas of Award: U. S. GPO, Washington, D. C.

COOPER, W. S. 1931. A third expedition to Glacier Bay, Alaska. Ecology. 12:61-95.

COULTER, H. W., D. M. HOPKINS, T. N. V. KARLSTROM, T. L. PEWE, C. WAHRHAFTIG, and J. R. WILLIAMS. 1965. Map showing the extent of glaciations in Alaska. U.S.G.S. Map I-415.

DERKSEN, S. J. 1974. Raised marine terraces southeast of Lituya Bay, Alaska. M.S. thesis. The Ohio State University. 84p.

_____. 1976. Glacial geology of the Brady Glacier region, Alaska. Ph.D. Dissert. The Ohio State University. 119p.

FIELD, W. O. 1947. Glacier recession in Muir Inlet, Glacier Bay, Alaska. Geog. Rev. 37:369-399.

_____. (ed.) 1975. Mountain glaciers of the Northern Hemisphere, v. 2. U. S. Cold Regions Research and Engineering Laboratory, Hanover, N. H. 932p.

GOLDTHWAIT, R. P. 1963. Dating the Little Ice Age in Glacier Bay, Alaska. 21st Internat. Geol. Cong. (1960). pt. 27:37-46.

_____, 1966. Evidence from Alaskan glaciers of major climatic changes. *In:* Sawyer, J.S., ed. Proc. Internat. Symposium on World Climate from 8000 to 0 B.C. Royal Meteorol. Soc. London. pp. 40-53.

_____. 1974. Rates of formation of glacial features in Glacier Bay, Alaska. *In:* Coates, D. R. Glacial Geomorphology: Publ. in Geomorphology. SUNY, Binghampton, N. Y. pp. 163-185.

GOLDTHWAIT, R. P., I. C. MCKELLAR, and C. CRONK. 1963. Fluctuations of Crillon Glacier system, southeast Alaska. Bull. Int. Assoc. Sci. Hydrol. 8(1):62-74.

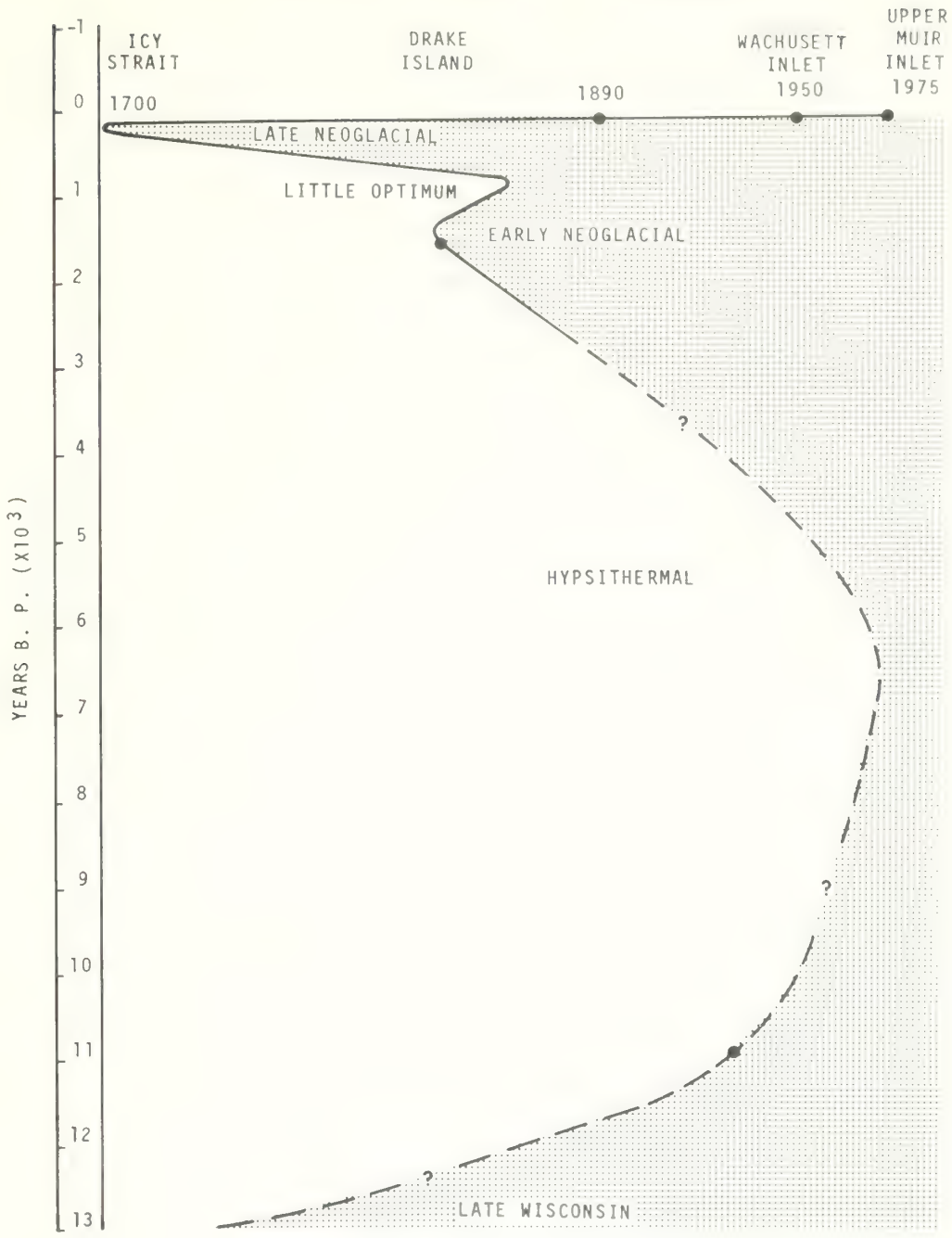

FIGURE 4. Major fluctuations of the ice between Upper Muir Inlet and the entrance to Glacier Bay. The dotted portion of the diagram represents glacierization.

HALLOCK, C. 1886. Our new Alaska. Forest & Stream Pub. Co., N. Y. 209p.

HASELTON, G. M. 1966. Glacial geology of Muir Inlet, southeast Alaska. Ohio State Univ. Inst. Polar Studies Rept. 18. 34p.

KLOTZ, O. J. 1899. Notes on glaciers of southeastern Alaska and adjoining territory. Geog. Journ. 14:523-534.

LAMB, H. H., R. P. W. LEWIS and A. WOODROFF. 1966. Atmospheric circulation and the main climatic variables between 8000 and 0 B.C.: meteorological evidence. *In:* Sawyer, J.S., ed. Proc. Internat. Symposium on World Climate from 8,000 to 0 B.C. Royal Meterol. Soc., London. pp. 174-217.

MCKENZIE, G. D. 1970. Some properties and age of volcanic ash in Glacier Bay National Monument. Arctic. 23:46-49.

MCKENZIE, G. D. and R. P. GOLDTHWAIT. 1971. Glacial history of the last eleven thousand years in Adams Inlet, southeastern Alaska. Geol. Soc. Amer. Bull. 82:1767-1782.

OVENSHINE, A. T. 1967. Provenance of recent glacial ice in lower Glacier Bay, southeastern Alaska. U. S. Geol. Survey Prof. Paper 575-D:198-202.

PETERSON, D. N. 1970. Glaciological investigations on the Casement Glacier, southeast Alaska. Ohio State Univ. Inst. Polar Studies Rept. 36. 161p.

REID, H. F. 1892. Studies of Muir Glacier, Alaska. Natl. Geog. Mag. 4:19-84.

_____. 1896. Glacier Bay and its glaciers. U. S. Geol. Survey Ann. Rept. 16, 1894-1895, pt. I:415-461.

VANCOUVER, G. A. 1798. A voyage of discovery to the North Pacific Ocean and round the world. 3 vols. and folio. London.

RESEARCH BY THE INSTITUTE OF POLAR STUDIES IN GLACIER BAY NATIONAL MONUMENT, ALASKA[1]

Richard P. Goldthwait and Garry D. McKenzie[2]

INTRODUCTION

The major disciplines involved in research in Glacier Bay National Monument by the Institute of Polar Studies are: glaciology, glacial geology (including both processes and history), and biology. This paper is a summary of important scientific results.

Since 1958, 25 field parties have worked in Glacier Bay National Monument (Table 1). Only two summer field seasons were omitted and several very early pre-Institute seasons (1933, 1934, 1936) initiated some of the studies. Most of the projects were supported by the National Science Foundation; however, other contributors included the Atomic Energy Commission, American Geographical Society, Institute of Polar Studies and Department of Geology and Mineralogy at The Ohio State University, National Park Service, and Sigma Xi. In several cases personal funds were utilized. The National Park Service provided logistic support, radio and mail service, and a staging base for all projects. Total research funds received from major federal granting agencies is over $250,000. Other funds made available for the projects total $21,000. A dollar amount for logistic support by the National Park Service within the Monument cannot be calculated but certainly exceeds this last figure.

The results of the research have been reported in journals, the Institute report series, and abstracts. The authors of these publications are identified with the projects and field seasons in Table 1. Thirty-five research papers and reports and 13 abstracts have resulted from these projects. In addition 11 advanced degrees (four M.Sc. and seven Ph.D.) resulted from Glacier Bay research.

GLACIOLOGY

Burroughs Glacier

The first glaciological project of the Institute in Glacier Bay was a study of the origin of ice structures and fabric in Burroughs Glacier (Figure 1) by L. Taylor (1962). For this wasting glacier, no longer fed from snow accumulation near the Canadian boundary, ablation and motion measurements were made, and the crevasse system, ice texture and ice fabric were studied. These indicators of ice-flow direction revealed that during Neoglacial time when ice was over 400 m deeper and fed from high snowfields 40 km to the northwest, the glacier flowed in one direction whereas during stagnation now the glacier flows in several different directions around hills as they emerge. The rate of lowering of the surface between 1948 and 1960 was 0.8 m a^{-1} at 500 m elevation and 6-8 m a^{-1} at 175 m elevation. Three kinds of ice were identified at the glacier surface: foliated ice, coarse-grained border ice, and very coarse-grained basal ice. Ice was found to adjust rapidly to changes in the stress field.

Larson (in prep. a) investigated the internal drainage of a stagnant residual of Burroughs Glacier. Annual ablation rates varied from 2.35 m of water at 275 m elevation to 3.33 m of water at 120 m elevation. About 3 m below the surface of the stagnant ice a water table fluctuated as much as 3 m in a day, from a low at 6:00 a.m. to a high at about 6:00 p.m. The interstitial water flow in stagnant ice was along spaces melted between ice crystals, and in fractures or shear planes. Permeability in the upper 8 m of ice averaged from 390 to 2900 liters m^{-2} d^{-1}; storage coeffecient ranged from .0046 to .0245.

Larson (in prep. b) returned to Burroughs Glacier in 1972 and 1973 to investigate in detail the hydrology of a larger portion of this glacier that is well below the equilibrium line but still is flowing from 0.2 to 6 m a^{-1}. Downwastage of the glacier is as much as 9 m a^{-1}; backwastage is as much as 0.2 km a^{-1}. Run-off from the glacier was correlated with the recorded melt on the glacier as divided into three subbasins. Some of the meltwater was found to be stored in the fracture and shear planes within the upper few meters of the glacier.

Crillon Glacier

Institute personnel studied the Crillon Glacier System in the northwestern portion of the Monument many years ago (1933, 1934, 1936) on the Harvard-Dartmouth Expeditions. Theodolite measurements on the ice cliff of South Crillon Glacier indicated a velocity of 145 m a^{-1} and a non-uniform discharge of icebergs concentrated at the close of each summer day. Three "firsts" for North America were recorded here: (1) seismic profiles in ice showed how a lake (Crillon) 100 m above sea level can be held in by a glacier (South Crillon) in a trough well below sea level; (2) glacier motion can be speeded up by summer melt or heavy rain (Washburn and Goldthwait 1937); and (3) surface motion in a heavily crevassed area can be very jerky with short (15- and 30-minute) interval displacements of 1 to 5 mm. These were later contrasted with the smooth "plug" sliding of a thin part of Casement Glacier (Goldthwait 1973).

The Institute restudy in 1961 showed that over the past two centuries Crillon glacier system has advanced slowly and regularly, unlike most northern hemisphere glaciers. The first historical records of ice position begin with La Perouse in 1786 (Flory 1927), followed in 1894 by Klotz (1899). From 1929 to 1961, the North Crillon Glacier was found to advance about 30 m a^{-1} and South Crillon Glacier advanced at 10 m a^{-1}. This is believed to indicate increased snowfall on the high Fairweather Range, since snowlines (equilibrium lines) on glaciers on lower peaks in the area moved higher by 300 m since 1880.

Investigations on the Casement Glacier (Figure

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TABLE 1. Scientists in field (Glacier Bay) with Institute of Polar Studies: 1958-76. Underline shows report authors; parentheses indicate laboratory only, not fieldwork.

1958	R. P. Goldthwait, W. O. Field
1959	L. Taylor, G. Burnes, R. P. Goldthwait
1960	L. Taylor, G. Haselton, R. Luce, and R. Jones
1961	R. P. Goldthwait, I. C. McKellar, C. Cronk, G. Haselton, and G. Burns
1962	R. J. Price, R. A. Welch, S. Calmer, R. P. Goldthwait
1963	G. Haselton, F. Larsen, R. Whitelaw, R. J. Price, R. P. Goldthwait
1964	G. Haselton, C. Weiman, K. Fitzpatrick, R. P. Goldthwait
1965	R. P. Goldthwait, H. F. Decker, D. M. DeLong, E. E. Good, M. D. Trautman, F. C. Ugolini, R. K. Burnard, D. Frickie, T. B. Goldthwait, T. R. Merrell, III, (E. D. Rudolph, F. Loewe), F. Preston, D. N. Peterson, J. Lindsay, M. Owens, P. Hooge, P. Darvall
1966	G. D. McKenzie, W. C. Lefler, T. R. Merrell, III, R. P. Goldthwait, D. N. Peterson, M. Mandt, G. Holdsworth, F. Erdman, T. Sanders, J. Carroll, C. B. Bull
1967	G. D. McKenzie, T. R. Merrell, III, D. Goldthwait, R. P. Goldthwait, D. N. Peterson, T. Croley, D. Goodman, P. Meisler, J. Moravek, J. States, P. Cress, R. Ellis, C. B. Bull
1968	None
1969	D. Mickelson, R. Votaw, R. P. Goldthwait
1970	D. Mickelson, G. Larson, R. Ward, J. Rose, W. A. Pettyjohn, R. P. Goldthwait
1971	R. P. Goldthwait
1972	G. Larson, R. P. Goldthwait, N. Ten Brink, P. H. Wu
1973	S. Derksen, R. Yost, R. P. Goldthwait, G. Larson, D. Larson, P. H. Wu
1974	S. Derksen, J. Mazgaj, R. P. Goldthwait
1975	S. Derksen, D. Rugh, R. P. Goldthwait
1976	None

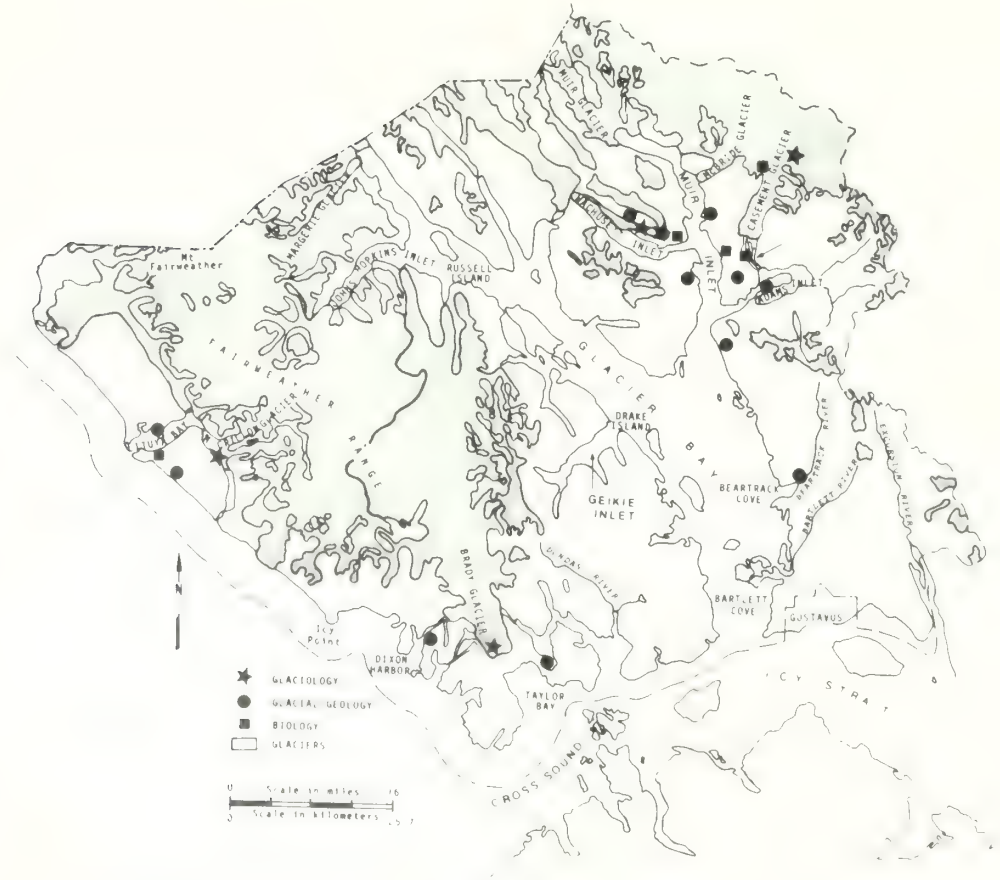

FIGURE 1. Glacier Bay National Monument and location of Institute of Polar Studies research projects in glaciology, glacial geology, and biology.

1) by Peterson (1970) during the 1965, 1966, and 1967 summer field seasons concentrated on assessing the mass and heat balances of this representative retreating glacier. Velocity measurements showed that over the three-year period the summer velocities varied, but in all cases, were greater than the winter velocities. Most of the observed annual, seasonal, and diurnal changes in surface velocity resulted from changes in quantity of free water at the glacier bed. In a tunnel near the ice margin, August basal velocities averaged 2.9 cm d^{-1} in 1966 and 2.6 cm d^{-1} in 1967. The flow of ice around artificial cubes (1.0 and 2.5 cm square) attached to bedrock at the base of the glacier was studied. The contribution from regelation slip (thaw-freeze) for objects between 1 and 2.5 cm in height was equal to that from plastic flow.

In two short heat balance studies, it was determined that the relative contributions of Q_R (radiation), Q_A (sensible heat), Q_L (latent heat), and Q_P (heat from rainwater) were 65, 19, 15, and 1 percent, respectively, The mass budget of the glacier for the year 1966-1967 was found to be negative: $-235 \pm 46 \times 10^9$ kg. which is consonant with its continuing retreat.

Brady Glacier

Most recently Derksen (1976) showed that the broad south end of Brady Glacier is advancing slowly onto outwash gravels and marine clay deposits in Taylor Bay. Like the Crillon Glacier termini the snow feeding grounds are in the high Fairweather Range where snowfall seems to have increased during this century. Recent nearly-open lateral moraines above Brady Glacier and its southwest arms were used to show the snowline (moraine ends) were about 123 m lower two thousand years ago than they are now. Furthermore, the glacier was 280 m thicker near its present lower end, scoring adjacent trees only a century ago according to tree ring count. It happened to end at the same place into Taylor Bay when John Muir made his first visit in 1880, but the outwash fan was half as big.

GLACIAL HISTORY

Muir Inlet in Hypsithermal and Neoglacial Time

Research on glacial geology has been concentrated on the glacial history over the 10,000 years since Wisconsin time. The history was read first from a stratigraphy (Figure 2) primarily in the eastern part of the Monument: Glacier Bay in 1958, 1972 (Goldthwait 1963b); Muir Inlet, 1963 and 1964 (Haselton 1966); Adams Inlet, 1966 and 1967 (McKenzie 1970); and Wachusett Inlet, 1959, 1969, and 1970 (Goldthwait 1963; Mickelson 1971).

The retreat of Wisconsin ice came first, leaving the Granite Canyon till. It was followed directly by marine invasion, indicated by the glaciomarine Forest Creek silts (with shells) found east of Muir Inlet up to 60 m elevation and dated 10,940 years B.P. (I-2395). The next stratigraphic unit, the Lower Van Horn sandy-gravel outwash accumulated in valleys during the long Hypsithermal time (7,000-4,000 B.P.) when temperatures were thought to be 1°C warmer than now; buried forests show tree populations like those today. Glaciers were retracted further than today but never disappeared. Between 4500 and 2200 B.P. lacustrine materials were deposited in many parts of Muir Inlet and outwash gravels were still building in some tributary valleys.

Although this Early Neoglacial activity does not record any glacier advances in Wachusett Inlet until 2735 B.P. (I-122), ice apparently was advancing in upper Glacier Bay, as at Reid Inlet, by about 4680 B.P. (Y-9). The major advance of the Muir System came during the Late Neoglacial. By 1560 B.P. (I-2301) ice had advanced through a lake in Adams Inlet and was moving south up one of the tributary valleys. A minor retreat, thought to correlate with Little Optimum time (A.D. 1150-1300) is recorded again in the area southeast of Adams Inlet by outwash. The final Late Neoglacial advance, often called Little Ice Age, brought ice even much further south to the mouth of Glacier Bay by A.D. 1700. Since then the remarkable retreat up the bay of over 100 km has taken place (Mirsky 1966).

Dundas River to Dixon Harbor

Not all glaciers of Glacier Bay Monument behaved exactly the same way but the timing is approximately the same. Most recently Derksen (1976) mapped the comings and goings of Brady Glacier and its three distributary lobes in the extreme southwest part of the Monument (Figure 1). Whereas Late Wisconsin ice (last maximum 15,000 or 12,000 B.P.) covered nearly all ridges and peaks near Muir Inlet, here on the outer coast it left extensive ridges and peaks exposed above 600 to 1000 m; faint bouldery lateral moraines and smoothed grooved bedrock surfaces show the ice limit in contrast to massive block fields above. When this ice, 1000 m thick in fiord channels, melted away (> 11,000 B.P.) the land was still depressed and the sea flooded in and around the coastal mountains leaving clay, silt, and shells. Hypsithermal time involved emergence, but far less glacial fill than at Muir Inlet as glaciers were further back and mountains were lower here. One radiocarbon date (4680 B.P., Y-9) confirms Early Neoglacial advance of Brady Glacier but the principal advances came at 2900 B.P. Unlike Muir Inlet the Late Neoglacial resurgence came as late as A.D. 1878.

Lituya Bay

The Lituya Bay area in the northwest part of the Monument was previewed and mapped by the Mt. Crillon Expeditions (Washburn 1935), and by Goldthwait et al. (1963) after the great earthquake-landslide waves had exposed shore areas. The North Crillon Glacier advanced down the Bay and out to sea several times during the Wisconsin Glaciation, but left ice-free areas 30 km to the northwest and to the southeast along the Pacific coast. Outwash and till from the last Wisconsin advance underlies a fossil forest dated at 9150 B.P. (I-547) in the outer bay. During Hypsithermal time the North Crillon Glacier and others were probably far from the ocean; but again during the Neoglacial cool period the ice advanced down Lituya Bay and built a moraine ridge just inside and on top of the massive Wisconsin lateral moraines. That this Little Ice Age glacier (400 to 1000 years ago) reached the same high lateral moraine as the colder Wisconsin glaciation 12,000+ years ago can only mean that Fairweather Range rose about 300 m higher during the years between glaciations (manuscript in preparation). Part of the Neoglacial moraine is dated at 1090 B.P. (I-548), but ice may have lingered until after 390 years B.P. (W-371). Some of this old ice was discovered still to exist beneath the mossy deep spruce forest north of Fish Lake (Post and Streveler 1976). Advance of this ice had not reached halfway down Lituya Bay by 1500 B.P. In prehistoric time the ice retreated rapidly; by 1786 it was about 5 km back of the present position.

A more subdued outer moraine 0.5 to 3 km outside the Wisconsin-Neoglacial "Solomons Railroad" was mapped in 1961 (Goldthwait 1963) but carefully investigated in 1972 by Derksen's party.

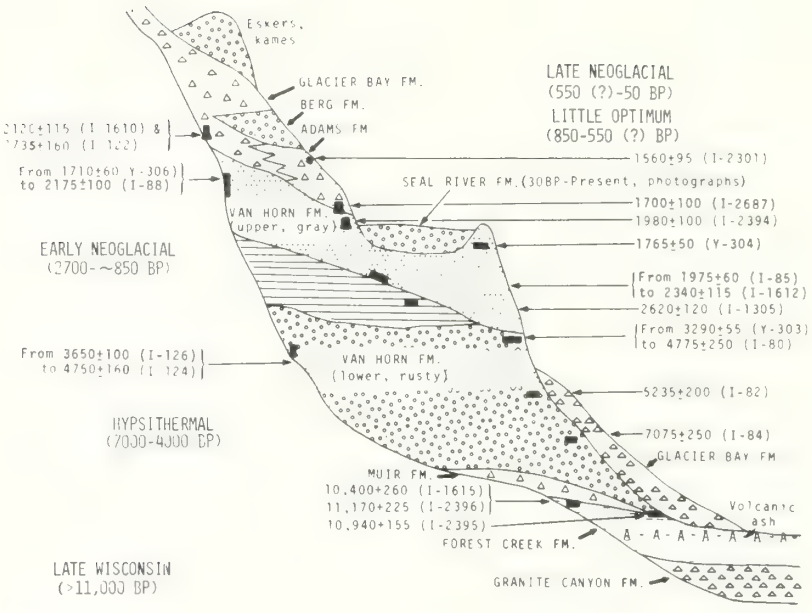

FIGURE 2. Composite stratigraphic section for eastern Glacier Bay region (Muir Inlet area). Dates are radiocarbon years B.P.

It extended out into the Pacific Ocean, in a large bulb of piedmont glacier. This happened at least as far back as Early Wisconsin (50,000+ B.P.) and probably as old as Illinoian time (125,000 B.P.) as judged by subdued forms and cavernously weathered boulders.

GEOMORPHOLOGIC PROCESSES

Coastal Benches

The outer (Pacific) coast of Glacier Bay National Monument has a 5-step foreland on the coast ranges from Icy Point to Fairweather River. These benches were first mapped and interpreted in the 1930's (Washburn 1936) as interglacial raised sea strands. Some Institute personnel confirmed this by traverses in 1961 (Goldthwait et al. 1963) and detailed study was completed by Derksen (1974). The lowest beach is not over 400 years old according to its subclimax forest, tree rings, and relics on it. An affiliated bench (+ 13 m), and sea cliff at distances up to 150 m behind it, dates from the post-Wisconsin marine flooding due to the isostatic depression which brought the silts and clays, with shells, into the Bay.

The next higher bench is 250 m wide and is identified all the way across Fairweather Fault from Glacier Bay mouth (+30 m) to Lituya Bay (+30 m); since it is covered by Early (?) and Late Wisconsin moraine, outwash, and striae it is more than 75,000 years old (Sangamon age). Only in the unglaciated refugia northwest and southeast of Lituya Bay are two still higher tilted terraces preserved (at 50-140 m and at 100-265 m). These are one to two km wide and no beach materials were found, yet the oldest moraine near Lituya Bay (Illinoian?) crosses them so they are more than 170,000 years old.

Unsorted Till Deposits

Each of the groups working on glacial stratigraphy devoted some attention to the genesis of glacial deposits as actually witnessed around retreating glaciers and as recorded by repeated photography. These culminated in Mickelson's study of the deglaciated area south of Burroughs Glacier (1971) and rates were summarized by Goldthwait (1974).

Mickelson's most unique contribution (1971) was a measure of the rates of basal till deposition at 15 places under the thinning Burroughs ice sheet. This was worked out from the stone orientations in different levels of remaining till; these corresponded to the shifting directions of ice motion around hill tops as they became exposed through the ice. From 0.5 to 5 cm a^{-1} of till was deposited, suggesting that most of the till is deposited by melting of bottom dirty ice during the last few centuries of ice occupation. Minor moraine ridges 0.5 to 4 m high are everywhere on land either side of Muir Inlet. Thought at first to represent the annual forward "winter push," because they are separated by annual retreat distances (Goldthwait 1963a), Haselton (1966) showed that some formed from ablation debris falling into crevasses or by meltout of

TABLE 2.

I	early pioneer,	*Dryas* and willow seedlings, horsetail	1 to 5
II	mat stage,	*Dryas* mats (4 m) and *Epilobium*	5 to 10
III	late pioneer,	scattered alder, willow, poplar (1-2 m)	10 to 15
IV	open thicket,	alder; tall but penetrable	20 to 25
V	closed thicket,	alder; tall, thick, intergrown	30 to 35
VI	poplar-line	poplar emerges above alder canopy	40 to 50
VII	spruce forest,	spruce emerge and dominate	75 to 90
VIII	spruce-hemlock forest,	mossy with bushy undergrowth	150 to 200
IX	hemlock-cedar forest,*	very tall, windfalls everywhere	10,000+

*Added from the outer coast, Burns (1961) and Yost (1972), both unpublished works.

heavily dirt-filled shear planes. Then Mickelson and Berkson (1974) showed that along Wachusett Inlet these formed parallel to a cliffed ice edge from basal till which squeezed up into the crevasses.

These minor moraines are draped like ribs over still smaller parallel ridges and grooves, 5 to 200 m long and 10 to 50 cm high, which are parallel to last ice motion. They were found to represent the squeezeup of wet till into a corrugated moving glacier sole, corrugated where thin ice passes over knobs or impounded boulders. Many exist as tails behind emplaced boulders (crag-and-tail) but they wash and slump away rapidly in the moist climate to become half as high in a decade.

Ice Contact and Outwash Features

Specific studies of the genesis of esker sand-gravel ridges were made below Casement Glacier by Price (1964) and next to Burroughs Glacier by Mickelson (1971). Many of the former were on or near the surface of a wide area of stagnant terminal ice; they formed in ice and draped over a basin by melting out during three decades. In the Wachusett area eskers were subglacially formed and covering ice melted out in about five years. The principal specific studies of kame terraces were done by McKenzie (1969) on a coarse gravel terrace deposited on decaying ice in Adams Inlet, and by Mickelson (1971) on a terrace on the valley side above Burroughs River when it flowed on the edge of the retreating ice lobe. Deposition occurs rapidly in one to three years but the ice beneath the gravel takes at least 10 to 50 years longer to melt away. McKenzie calculated the heat penetration in summer at 5.5 J m^{-2} s^{-1}.

Outwash and delta fans took still longer to form. First it was discovered by radiocarbon dating of Hypsithermal forests in gravels 100 m thick in Wachusett Inlet that the rate of accumulation was very regular over long times; 1.4 m per century or 7000 years for the whole terrace fill (Goldthwait 1963b). A small delta-fan in front of North Crillon Glacier built into deep fiord water since about 1920 and the ice has advanced 0.5 km over it during construction. It grew in fits and starts (1933-48 and 1958-61) due to adjacent landslides and available material on one side of the glacier.

Most diagnostic of the character and rate of ice downwastage in valleys on land are the slanting ice-marginal channels cut across low ridges or obliquely along long hillside slopes. Some are hanging in-and-out (U-shaped) channels formed from englacial tubes in a month or two. Several long submarginal channels formed on one slope in one year, but a few short deep channels across ridge crests carried 1 to 3 m^3 sec^{-1} meltwater for two or three melt seasons (Mickelson 1971).

BIOLOGY

Casement Glacier

In 1962 a modest program on the distribution of fauna and flora in the area south of Casement Glacier was appended to the glacial geology project for that summer. Observations by Welch (1965) on vegetation, mammals, birds, and fish, illustrated the expected increase in species 4 to 8 km away from the retreating ice fronts. Later, ice worms (*Mesenchytraeus solifungus*) were studied on Casement Glacier and in the laboratory by Goodman (1971). Worm distribution was found to be related to the distribution of algae, which they ingested, and worm concentrations were high in snow over crevasses. The worms were found to enter the snow and ice during the day and return to the surface at night. Oxygen consumption at 0°C is 52 µl $g^{-1}hr^{-1}$. The worms autolyzed and disintegrated above 20°C.

Muir Inlet

In 1965 a large one-season ecological study of Muir Inlet region resulted in a nine-part report (Mirsky 1966) aimed at the succession of plants, insects, birds, mammals, and freshwater fish in newly exposed areas of land. Background was the documented exposure of nunataks and new belts of lowland, 30-150 m wide each year. New shore was being exposed also at over 4 cm a^{-1} because of isostatic uplift of the land as the ice unloaded it. Climate was analyzed by a comparison of nearby all-year stations and the summer observations made in Muir Inlet (Loewe in Mirsky 1966). Glacier Bay has an oceanic climate characterized by a small annual and diurnal temperature range, by high relative humidity and cloudiness, heavy precipitation, and rather strong winds. For the Muir Inlet area, the mean monthly temperature for January was estimated to be about -5°C. Precipitation everywhere in Glacier Bay is probably above 1250 m a^{-1}. New soils (regosols) developed into incipient podzol after 65 years near the terminus of Casement Glacier and showed full

development in the Bartlett Cove terminal moraine which is 250 years old (Ugolini in Mirsky 1966). The maritime climate is conducive to an accelerated rate of soil development so a complete podzol formed in approximately 150 years.

Eight intergrading stages in plant succession, given in Table 2, were recognized (Decker in Mirsky 1966) and added detail to Cooper's (1931) classic work. The insects (DeLong in Mirsky 1966) in the Muir Inlet area showed that the first aquatic insects to appear behind the melting glaciers are larvae of certain mosquitoes and black flies. Associated with these are small predaceous diving beetles and a species of water boatman. The early terrestrial species are usually found some 15 to 20 years after glacier recession with plant lice and jumping plant lice on the early alders and willows. More species occur with each older recessional zone until a climax is reached in the spruce forest and strawberry meadow some 75 years after glacier recession. DeLong also observed an unusual new species of leaf-hopper, *Macrosteles fascifrons* (subspecies) living on salt grass on a tidal flat, which is submerged twice daily in 2°C meltwater containing icebergs.

Bird associations with these habitats begin nearest the glacial front with snow bunting and rock ptarmigan (Trautman in Mirsky 1966). Several distinctive diverse bird associations lead finally to the chestnut-backed chickadee, varied thrush, and pine grosbeak in Sitka spruce and western hemlock forest.

Mammal distribution (Good in Mirsky 1966) showed that the first mammals to invade new terrain about 25 years after deglaciation are the wandering shrew and the deer mouse. The red-backed vole which is one of the most characteristic mammals of the climax forest and the masked shrew invade when there is a thick spruce needle carpet after 100 years. Larger mammals of several species moved freely throughout the area so were not good indicators of habitat change: mountain goats abundant, coyotes common, wolves infrequent, tracks of wolverine and river otter on the coast. Tracks of both brown and black bears were seen in various parts of the area and black bears were resident in 100-year spruce forests. The red squirrel and the pine marten were present a few kilometers still further south and in the spruce-hemlock area.

Collections of freshwater fish in the Muir Inlet area were small and all fish are tolerant of salt water: Dolly Varden trout, chinook salmon, silver salmon and threespine stickleback (Merrell in Mirsky 1966). The ecological succession in Muir Inlet is determined by plant cover and the stages of succession are more reliable for terrestrial habitats than are aquatic habitats (Rudolph in Mirsky 1966). These results may help us to understand the succession that occurred following the Wisconsin glaciaiton, at least on the coastlines.

Lituya Bay

Still older forests leading to the preglacial "refugium" southeast of Lituya Bay showed (Burns, unpubl.) a three-step transition from spruce, moss, and vaccinium with some hemlock in the 300 to 400 year old Neoglacial area, then tall hemlock dominant spruce forest in areas last occupied in Wisconsin time or cedar and hemlock forest in Illinoian (Early Wisconsin) or older area. The raised beach coastal areas showed similar major steps (Yost, unpubl.) from strawberry and young Sitka Spruce on the lowest Late Neoglacial beach (5 m) to mature spruce-hemlock on the Hypsithermal (13 m) bench to cedar-hemlock on the interglacial (30 m) bench.

Burroughs Glacier

Investigations of the metabolic patterns of vascular plants in successional habitats, using acetate-2-^{14}C incubations, were made by P. H. Wu (1975). She found that the relative radioactivity within the alcoholic soluble fraction of each species reflects its distribution in the successional communities. A high level of ^{14}C-sugars was present in plants of the pioneer community; on the other hand a high level of ^{14}C-organic acids was present on the plants of the forest community.

PROSPECT

The most critical missing element in the glacial history is now a detailed and definitive study of Geikie and Hugh Miller Inlets (and Reid Glacier) to define the Wisconsin-Holocene glacier fluctuations (McKenzie). Excursion Inlet to the east holds unknown potential but LaPerouse Glacier on the outer west coast has clear sets of moraines related to several ice advances and crossing the interglacial marine benches (Derksen). This area could be coupled with glaciology; it is the one large ice cliff, formerly and now, right in the Pacific Ocean. Long-term meteorological information, and especially snowfall, in its upper reaches and on Brady Glacier divide (both sides of Fairweather Range) and on upper Casement ice divide; all of these involve glacier budget and predict the future of most glaciers from the Coast inland. Glacial process studies of the early and middle Neoglacial lakes along the northeast edge of the Bay (Goodwin), and of glaciomarine sediments in the fiords (Powell) are planned now. A concluding study of the drumlins in Muir Inlet is still needed (Mickelson) but the discussion of geological evidence for the rise of land by isostacy is in preparation (Goldthwait).

LITERATURE CITED

COOPER, W. S. 1931. A third expedition to Glacier Bay, Alaska. Ecol. 12:61-65.

DERKSEN, S. J. 1974. Raised marine terraces southeast of Lituya Bay, Alaska. M.S. Thesis. Ohio State Univ. 84p.

_____. 1976. Glacial Geology of the Brady Glacier Region, Alaska. Ohio State Univ., Inst. Polar Studies Rept. 60. 97p.

FLORY, C. H. 1927. The Alaskan adventures of Jean Francois Galoripde La Perouse. Alaska Mag. 1(3):109.

GOLDTHWAIT, R. P. 1963a. Grooved tills and minor moraine ridges in front of receding glaciers in Alaska (abs.). Ohio Acad. Sci. Abs. of Papers 72nd Annual Meeting, Wilberforce, Ohio.

_____. 1963b. Dating the Little Ice Age in Glacier Bay, Alaska. 21st Internat. Geol. Congr. (1960. Pt. 27:37-46.

GOLDTHWAIT, R. P., I. C. MCKELLAR and C. CRONK. 1963. Fluctuations of Crillon Glacier system, southeast Alaska. Bull. Internat. Assoc. Sci. Hydrol. 8(1):62-74.

GOLDTHWAIT, R. P. 1973. Jerky glacier motion and melt water. *In:* Symposium on the Hydrology of Glaciers. Internat. Assoc. Sci. Hydrology, Pub. 95:183-188.

_____. 1974. Rates of formation of glacial features in Glacier Bay, Alaska. *In:* Coates, D. R. ed. Glacial Geomorphology: Publ. in Geomorphology. SUNY, Binghamton, N. Y. pp. 163-185.

GOODMAN, D. 1971. Ecological investigations of ice worms on Casement Glacier, southeastern Alaska. Ohio State Univ., Inst. Polar Studies Rept. 39, 59p.

HASELTON, G. M. 1966. Glacial geology of Muir Inlet, southeast Alaska. Ohio State Univ., Inst. Polar Studies Rept. 18. 34p.

KLOTZ, O. J. 1899. Notes on glaciers of southeastern Alaska and adjoining territory. Geog. Journ. 14(5):523-534.

LARSON, G. J. (in prep. a) Internal drainage of stagnant ice in Burroughs Glacier, southeast Alaska. Ohio State Univ., Inst. Polar Studies Rept. 65.

_____. (in prep. b) Meltwater storage in a temperate glacier. Ohio State Univ., Inst. Polar Studies Rept. 66.

MCKENZIE, G. D. 1969. Observations on a collapsing kame terrace in Glacier Bay National Monument, South-Eastern Alaska. J. Glaciol. 8(54):413-435.

_____. 1970. Glacial geology of Adams Inlet, southeastern Alaska. Ohio State Univ., Inst. Polar Studies Rept. 25. 121p.

MICKELSON, D. M. 1971. Glacial geology of the Burroughs Glacier area, southeastern Alaska. Ohio State Univ., Inst. Polar Studies Rept. 40, 149p.

MICKELSON, D. M. and J. M. BERKSON. 1974. Till ridges presently forming above and below sea level in Wachusett Inlet, Glacier Bay, Alaska. Geografiska Annaler 56A(1-2):111-119.

MIRSKY, A. (ed.) 1966. Soil development and ecological succession in a deglaciated area of Muir Inlet, southeast Alaksa, by R. P. Goldthwait, F. Loewe, F. C. Ugolini, H. F. Decker, D. M. DeLong, M. B. Trautman, E. E. Good, T. R. Merrell, III, and E. D. Rudolph. Ohio State Univ., Inst. Polar Studies Rept. 20. 167p.

PETERSON, D. N. 1970. Glaciological investigations on the Casement Glacier, southeast Alaska. Ohio State Univ., Inst. Polar Studies Rept. 36. 161p.

POST, A. and G. STREVELER. 1976. The tilted forest: glaciological-geologic implications of vegetated Neoglacial ice at Lituya Bay, Alaska. Quaternary Res. 6:111-117.

PRICE, R. J. 1964. Land forms produced by the wastage of the Casement Glacier, southeast Alaska. Ohio State Univ., Inst. Polar Studies Rept. 9. 24p.

TAYLOR. L. D. 1962. Ice structures, Burroughs Glacier, southeast Alaska. Ohio State Univ., Inst. Polar Studies Rept. 3. 110p.

WASHBURN, H. B., JR. 1935. The conquest of Mount Crillon. Nat. Geog. Mag. 67(3):361-400.

_____. 1936. The Harvard-Dartmouth Alaskan Expeditions, 1933-34. Geog. Journ. 87(6): 481-495.

WASHBURN, B. and R. P. GOLDTHWAIT. 1937. Movement of South Crillon Glacier, Crillon Lake, Alaska. Bull. Geol. Soc. Amer. 48(11):1653-1664.

WELCH, R. A. 1965. Ecological observations in the Muir Inlet area, Glacier Bay National Monument, Alaska. Ohio State Univ., Inst. Polar Studies Rept. 15. 19p.

WU, P. H. 1975. Metabolic patterns of ^{14}C incorporation by selected vascular plants following field incubations with acetate-2-^{14}C in two plant successional stages in Glacier Bay, Alaska. Plant & Cell Physiol. 16(6):1017-1025.

AEOLIAN THEORY REEXAMINED FOR THE WHITE RIVER GROUP[1]

J. C. Harksen[2], D. K. Olson[3] and E. A. Gordon[4]

INTRODUCTION

The origin of the White River Group concerning its stratigraphy, mineralogy, paleontology, and paleoclimatology within the Badlands National Monument and other areas in South Dakota is one of controversy. Many believe, however, that everything about the White River is known and that little is to be gained by further study. But, to quote the words of the late J. D. Bump (1951:35), "There is probably more knowledge to be gained by future research in the paleontology, lithology, and stratigraphy than has been compiled in the last 100 years."

Therefore, the authors, following the suggestion of J. D. Bump, present a preliminary report showing the results of their recent fieldwork.

Since the earliest exploration, the White River Badlands of South Dakota have been known for their weird and desolate exposures of middle to late Cenozoic strata as well as their incredibly rich vertebrate fauna. Early geologists, F. V. Hayden, John Evans, E. D. Cope, and Joseph Leidy, who first worked with the stratigraphy and fauna of the White River Group in the 1850's and 1860's, formulated the theory that the beds were lacustrian in origin. They felt the sediments were eroded from high areas in the Rocky Mountains and Black Hills and were deposited in a series of fresh water lakes. These lakes were thought to have varied in position and extent throughout the period of Tertiary deposition in the Great Plains. It was postulated that the lakes were structural in origin and resulted from either a downwarping to the west or the uplift of a barrier to the east.

The lacustrian theory was held as official dogma until W. D. Matthew (1899) published a paper entitled "Is the White River Tertiary an Aeolian Formation?" This paper seemed to spark a flurry of papers questioning the lacustrian theory. W. D. Johnson (1901) held the White River to be fluviatile, E. Fraas (1901) proposed a fluviatile/aeolian origin, and J. B. Hatcher (1902) proposed a fluviatile origin. Of all these papers Hatcher's seems to have held the greatest popularity and for 75 years has been basically accepted as the approved theory for the deposition of the White River Group.

STRATIGRAPHY

The beginning of the Oligocene deposition across the Great Plains coincides roughly with the beginning of the main phase of volcanism in the Larimide Orogeny. Russell (1954:65) in reference to the Larimide Orogeny, states "From the known ages of the pre-orogenic and post-orogenic sediments associated with these mountains it was shown that while there were late Cretaceous movements, and some in the Paleocene, the major diastrophism was of Eocene age, mostly in the early and late parts of that epoch." He goes on to state, "In the Black Hills Region the oldest post-orogenic deposits are of early Chadronian age (Yoder and Lower Chadron)."

In the highly colored Badlands National Monument the majority of the exposures are of the White River Group. The White River Group is composed of silts and clays which range through pastel reds, greens, browns, and grays. The White River Group is unconformably underlain by the red and yellow Interior Paleosol which was formed during the early Oligocene on the dark-gray Cretaceous (marine) Pierre Shale. The pastel Sharps Formation (Miocene) conformably overlays the White River Group.

The White River Group, in its type area of southwestern South Dakota, is approximately 190 meters (630 feet) thick. It is composed of the Chadron (lower) and Brule Formations. As it lies unconformably upon the eroded surface of the Pierre Shale, the Chadron is variable in thickness ranging from 2 meters (7 feet) to 54 meters (180 feet) in thickness. Generally it is composed of a noncalcareous green massive clay that weathers to a loose popcorn surface. The Chadron appears as a series of low rolling mounds which gives rise to the term "haystack topography." In several exposures the upper part of the Chadron contains several beds of a hard, dense pond limestone. In many places the base of the Chadron contains a basal conglomerate and/or fluviatile channel sands. These channel sands are commonly referred to in the literature as the Titanothere Channels.

In its type section area, the Brule Formation consists of 135 meters (450 feet) of massively bedded, flat lying, calcareous silts and clays. This unit has a high volcanic ash content, and is various pastel shades of red, brown, yellow, green, and gray. The Brule is more massive towards the top. However, in most areas, a sequence of alternating hard and softer beds gives rise to a tread and riser topography. Bump (1956) divided the Brule Formation into two members, the Scenic (lower) and Poleslide. Through strict definition any channel deposits occurring in the Scenic Member are called *Metamynodon* channels while any channels occurring in the Poleslide are called *Protoceras* channels. Further descriptions of the fauna, stratigraphy, and history of exploration of the White River Group can be found in Harksen and Macdonald (1969a, 1969b) and Harksen (1969).

GEOGRAPHIC AREA OF EXPOSURE

The White River Group of South Dakota is but a remnant of a thick sequence of continental beds deposited, during the Oligocene Epoch, along the eastern flanks of the Rocky Mountains and extending far out onto the Great Plains. These sediments were spread over a vast area, ranging from

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western Montana (Douglass, 1901) on the west to central South Dakota (Petsch, 1953) on the east and from the Cypress Hills of Alberta and Saskatchewan, (Russell, 1972) on the north, southward to the State of Chihuahua in northern Mexico (Wilson et al., 1972). While these beds may be known by different geographic place names in different areas, they are still part of one interconnected cycle of deposition.

Major deposits of the White River are found in four states: Colorado, Wyoming, Nebraska, and South Dakota. Within South Dakota, the bulk of these deposits are located to the southeast of the Black Hills and in the region of the Badlands National Monument. Small outliers are found on many buttes such as Slim Buttes, Castle Rock Butte, and the east and west Short Pine Hills, to name a few, which are scattered across the northwestern part of South Dakota. These outliers give mute testimony to the fact that at one time most of South Dakota, indeed the Great Plains itself, must have been covered by a continuous blanket of White River sediment.

Work by Darton and Paige (1925) and others has shown that in many areas of the Black Hills there are scattered remnants of the White River Group. The largest of these remnants are located on the periphery of the Hills, on the divides between Beaver and French Creeks, French and Grace Coolidge Creeks, and Battle and Spring Creeks. In addition, there are at least 15 outliers which are present on the igneous-metamorphic core of the Black Hills themselves. These are found up to an elevation of 6,300 feet (Bump, 1951) which is less than a 1,000 feet below the maximum elevation in the Black Hills and 3,500 feet above the average elevation in the Badlands National Monument. McGrew (1953) reports similar high altitude deposits in the Medicine Bow and Laramie Mountains of Wyoming.

If we assume that the White River Group was indeed fluviatile in origin we would expect to find very course deposits in the uplands regions grading into finer and finer deposits as we advanced out onto the plains. In this respect, the small deposit of the White River Group 1½ miles west of Johnson's Siding (sec. 36, T. 2 N., R. 5 E., Pennington County, South Dakota) presents some interesting insight into the depositional history of the group as a whole. This exposure is a roadcut where 4 meters of strata are exposed. Lithologically it is a reddish-brown to greenish silty clay that exhibits color banding and contains stringers of locally derived schist pebbles. These schist pebbles are the only characteristic that distinguishes the Johnson's Siding deposit from those in the Badlands. Preliminary x-ray diffraction studies show that the dominant clay-mineral in the Johnson's Siding section is smectite the same mineral that is dominant in the non-channel portion of the Brule Formation in its type section area.

MINERALOGY

Preliminary mineralogic studies of the Brule Formation have been conducted on samples collected in the type section areas of the Scenic and Poleslide Members (Bump, 1956; Harksen and Macdonald, 1969b). Twenty-seven samples were collected from this 135-meter (450-foot) thickness of strata that represent at least one sample of each obviously different type of lithology. While chemical, petrological, and x-ray diffraction analyses of these samples are far from complete, some interesting facts are coming to light.

X-ray diffraction studies on the clay mineralogy of 19 samples are now complete (R. L. Stach, personal communication). These studies show that in 17 of these samples, smectite is the dominant clay mineral. In one sample smectite and illite are present in equal amounts and in one sample illite is the dominant clay mineral. It is of special significance that the 17 samples in which smectite is the dominant clay mineral, all were collected from the massive flat-lying sequence of beds of predominantly silt and clay-sized sediment. The two samples that contain significant or dominant quantities of illite were collected from the one sedimentary feature of obvious fluviatile origin--the large *protoceras* channel located on the south side of Sheep Mountain Table. Harksen and Macdonald (1969b:9, 12, 13) present additional stratigraphic data on this particular channel deposit. Grim (1968) reports that smectite is usually formed by the alteration of volcanic ash in either a marine or a very dry continental environment. He also cites a paper by Grim and Varnet, who in studying bottom sediments from the Mediterranean Sea, found that the smectite present was of volcanic origin and was being altered to mix-layered structures which in turn were altered to illite. Grim concludes that an interval of geologic time without much volcanic activity, without large areas of relatively low rainfall, and/or with large areas of lateritic weathering would produce little smectite.

The percentage of calcite has been calculated for 19 of the 27 samples (R. L. Stach, personal communication). The percentage ranges from 0 percent for a tan clay collected 28.5 meters (95 feet) above the base of the Poleslide to 43.6 percent for a tan silty claystone collected 7.5 meters (25 feet) above the base of the Scenic. The mean amount of calcite present in the samples is 15.3 percent. As the samples were collected in a manner so as to reflect lithologic diversity and not at equal unit levels, the figure above is not a precise indication of the calcite content of the formation as a whole. However, when the individual sample percentages are weighted according to the thickness of strata that they represent, the calcite percentage for the formation as a whole drops to 13.0 percent, an extraordinarily high percentage for a stratigraphic unit that the authors believe to have been formed primarily from volcanic ash and its weathering products. The authors feel, in the light of the high smectite content of the rock and its depositional climatactic significance, that the calcite is post-depositional in origin and further indicates a climate where evaporation exceeds rainfall. This is substantiated by Dunbar and Rogers (1957:233) who state:

> $CaCO_3$ may also be deposited chemically in the soils of semi-arid or arid regions, where lime-bearing water evaporates instead of finding its way to the water table. In these areas it may form concretionary masses in the subsoil (as in the B horizon of prairie soils) or masses or layers close to the surface (as in the A horizon of more desert soils), producing the widespread calcrete deposits of many arid regions, for example, the caliche of parts of western North America.

CONCLUSIONS

The authors believe that the fluviatile theory for the origin of the White River Group be re-examined for the following reasons: (1) the scarcity of obvious fluviatile characteristics; (2) the uniformity of sediment size from high in the Black Hills to far out onto the plains; (3) the many deposits on the igneous-metamorphic core of the Black Hills; and (4) the high content of volcanic debris and its weathering products in the sediments themselves, points to a primarily aeolian origin for these deposits. Our investigations lend credence to the work of W. D. Matthew (1901) who regarded the White River ". . . as

being a subaerial (aeolian) deposit, of similar origin to the prairie loess of western Kansas and elsewhere." Fluviatile deposition did play at least a part in the deposition of the White River Group as shown by the obvious fluviatile origin of the Crazy Johnson and Peanut Peak Members of the Chadron Formation in their type localities (Clark 1954) and by the occasional *Metamynodon* and *Protoceras* channels found inthe Brule Formation. For the most part, the White River Group is composed of massive flat-lying beds with little indication of the channeling, ripplemarks and cross-stratifications that are generally thought of as being indicative of fluvial deposits. However, further work on the stratigraphy, mineralogy, and paleontology is necessary to completely prove or disprove our belief of an aerolian origin.

LITERATURE CITED

BUMP, J. D., Ed., 1951, Guidebook Fifth field conference of the Society of Vertebrate Paleontology in western South Dakota: Museum of Geology of the South Dakota School of Mines and Technology, 85 p.

BUMP, J. D., 1956, Geographical names for members of the Brule Formation of the Big Badlands of South Dakota: Am. Jour. Sci., V. 254, p. 429-432.

CLARK, J., 1954, Geographical designation of the members of the Chadron Formation in South Dakota: Annals of the Carnegie Museum, v. 33, p. 197-198.

DARTON, N. H., and Paige, S., 1925, Central Black Hills Folio, South Dakota: U.S. Geological Survey Atlas 219, 34 p.

DOUGLASS, E., 1901, Fossil mammalia of the White River Beds of Montana: Trans. Am. Philos. Soc., v. 20, art. 5, p. 237-279.

DUNBAR, C. O., and Rogers, J., 1957, Principles of Stratigraphy: John Wiley and Sons, New York, 356 p.

FRAAS, E., 1901, On the aqueous vs. eolian deposition of the White River Oligocene of South Dakota: Science, v. 14, p. 211-212.

GRIM, R. E., 1968, Clay mineralogy: McGraw-Hill, New York, 596 p.

HARKSEN, J. C., 1969, Geology of Badlands National Monument, *in* Larson, J. W., (ed), Natural Resources basic data for Badlands National Monument: National Park Service (Scientific field team report, p. 61-81).

HARKSEN, J. C., and Macdonald, J. R., 1969a, Guidebook to the Major Cenozoic deposits of southwestern South Dakota: S. Dak. Geol. Survey Guidebook 2, 103 p.

HARKSEN, J. C. and Macdonald, J. R., 1969b, Type sections for the Chadron and Brule Formations of the White River Oligocene in the Big Badlands, South Dakota: S. Dak. Geol. Survey Rept. Inv. 99, 23 p.

HATCHER, J. B., 1902, Origin of the Oligocene and Miocene deposits of the Great Plains: Am. Philos. Soc. Proc., v. 41, p. 113-131.

JOHNSON, W. D., 1901, The high plains and their utilization: U.S. Geol. Survey 21st Annual Report, p. 601-741.

MCGREW, P. O., 1953, Tertiary deposits of southeastern Wyoming: Wyoming Geological Association Guidebook, Eighth annual field conference; Laramie Basin, Wyoming and North Park, Colorado, p. 61-64.

MATTHEW, W. D., 1899, Is the White River Tertiary an Aeolian Formation?: American Naturalist, v. 33, p. 403-408.

MATTHEW, W. D., 1901, Fossil mammals of the Tertiary of northeastern Colorado: Amer. Mus. Nat. Hist. Bull., v. 7, p. 355-447.

PETSCH, B. C., 1953, Geologic map of South Dakota: S. Dak. Geol. Survey map.

RUSSELL, L. S., 1954, The Eocene-Oligocene transition as a time of major orogeny in western North America: Trans. Royal Soc. Canada, v. 48, ser. 3, sec 4, p. 65-69.

RUSSELL, L. S., 1972, Tertiary mammals of Saskatchewan, Part II; The Oligocene Fauna, non-ungulgate orders: Royal Ontario Museum, Life Sci. Contrib., v. 84, p. 1-96.

WILSON, J. A., Groat, C. G., Schiebout, J. A., Stevens, J. B., Stevens, M. D., Walton, A. W., and Wood, A. E., 1972, Vertebrate paleontology and continental stratigraphy field trip, Big Bend area, Texas: Texas Memorial Museum, 43 p.

GENESIS OF THE EROSIONAL FORMS OF BRYCE CANYON NATIONAL PARK[1]

Robert C. Lindquist[2]

INTRODUCTION

Bryce Canyon National Park is noted for its unusual, intricately carved, and colorful erosional forms. Encompassing almost the entire eastern escarpment of the Paunsaugunt Plateau, the Park offers the visitor not only views of a veritable lithic forest of walls, pinnacles, spires, arches, buttresses, grottos, and other myriad forms, but also vast vistas over much of southwestern Utah and Arizona.

Standing on the highest "step" of the series of escarpments rising northward from the Grand Canyon, the Paunsaugunt Plateau is bounded on three sides by the Pink Cliffs of the Wasatch Formation. This plateau is a member of a group of plateaus which owe their origin to a series of step faults (Figure 1). On the western side of the plateau, the Sunset Cliffs are formed on the fault scarp of the Sevier Fault. The eastern margin of the block on which the plateau is formed, is bounded by the Paunsaugunt Fault along which it is the downthrown side. Along this margin, the escarpment has a dual aspect of both an obsequent fault-line scarp and an erosional escarpment. On the southern margin, the escarpment is erosional in origin, while to the north, it is bounded by the Black Mountains formed on the Sevier Plateau Volcanics.

The characteristics of the escarpment within the Park make it one of the more unique in the United States. In few, if any, other areas are such erosional forms created. This uniqueness is largely a result of the lithology of the Wasatch Formation and its response to the types and rates of surface processes acting on it. Even if the hoodoos are not considered, the escarpment form itself possesses characteristics which tend to distinguish it from the other escarpments of the area.

Despite the unusual nature of this escarpment and its status as a National Park, no detailed studies exist concerning its form or origin or the genesis of the erosional forms developed along it.

GENERAL ESCARPMENT CHARACTERISTICS

Due to the varying conditions of lithology and the degree of penetration of the Wasatch Formation along the escarpment, a number of slope processes and forms prevail, giving each section of the Park a distinctive appearance (Figure 2). In the northern segment of the Park north of Fairyland Canyon, the Wasatch Formation is not penetrated and few resistant beds are exposed or differentially weathered rapidly enough on the slopes to produce a high density of hoodoos. Slope retreat is almost entirely by gullying action and, combined with the low hoodoo density, the result is an appearance akin to a "normal" badland topography.

In the middle segment of the Park containing the main amphitheater, the entire Wasatch Formation has been penetrated in the gullies (Figure 2, Sunset Point). The more resistant beds either stand out as small scarps or as the several levels of caprock under which the walls are formed. In this section, slope form and retreat are dependent on local lithologic controls. Over most of the amphitheater, the main process governing slope form is still that of gullying. However, as one moves southward, the elevation of the plateau increases and new beds, more massive and resistant, make their appearance in the upper part of the section (Figure 2, Inspiration Point). In these beds, depending on the lithology, slope retreat may be governed by slab failure, granular disintegration, and some rock avalanching and rock falls.

In the southern section, not only has the Wasatch Formation been breached, but the underlying formations are also deeply incised. The base of the Wasatch is now high on the slopes although it may not be fully exposed due to a cover of talus. The massive limestone cap which began in the middle segment continues on to the southern tip of the Park at Rainbow Point. Vertical walls produced by slab failure along the joints occur on both the cap and lower half of the section. Between the vertical scarps, the hoodoos are formed on the gullied beds of alternating resistance which, under these conditions, form roughly 50° slopes.

LITHOLOGY

Few detailed studies have been done on the stratigraphy or lithology of the beds of the Wasatch Formation in the Bryce Canyon area. Brox (1961) provided data on a section near Bryce Point including thickness of the beds, percent composition of the carbonate, clay and silt, and sand fractions and also clay groups. No dolomite was reported in this study and Gregory (1951) makes only passing reference to some of the beds being partially dolomitized.

This past year a study was done on a section along the North Campground rim where 15 beds are exposed in the walls. The walls are capped by a carbonate cemented sandstone up to 12 feet thick with the underlying beds ranging from thin shaly transitional units a few inches thick to massive beds up to 25 feet thick.

X-ray diffractometry used on finely ground untreated samples revealed only the presence of calcite, dolomite, and quartz. No gypsum or other minerals appeared in any of the patterns. Subsequent analysis for the dolomite-calcite ratio showed that in 7 of the 15 beds dolomite is the dominant carbonate, and in two of the beds it was entirely dolomite.

The samples were then treated to obtain samples of the clays which were also examined by X-ray diffractometry. Clay groups tentatively identified by their basal reflections are dominantly illites, chlorites, and possible kaolinite. No

[1]The author would like to express his appreciation to the personnel of the National Park Service at Bryce Canyon National Park, particularly Charles Budge, the former Superintendent, and George Neusaenger, Chief Park Ranger I & RM, for the assistance provided during the field studies in the Park.

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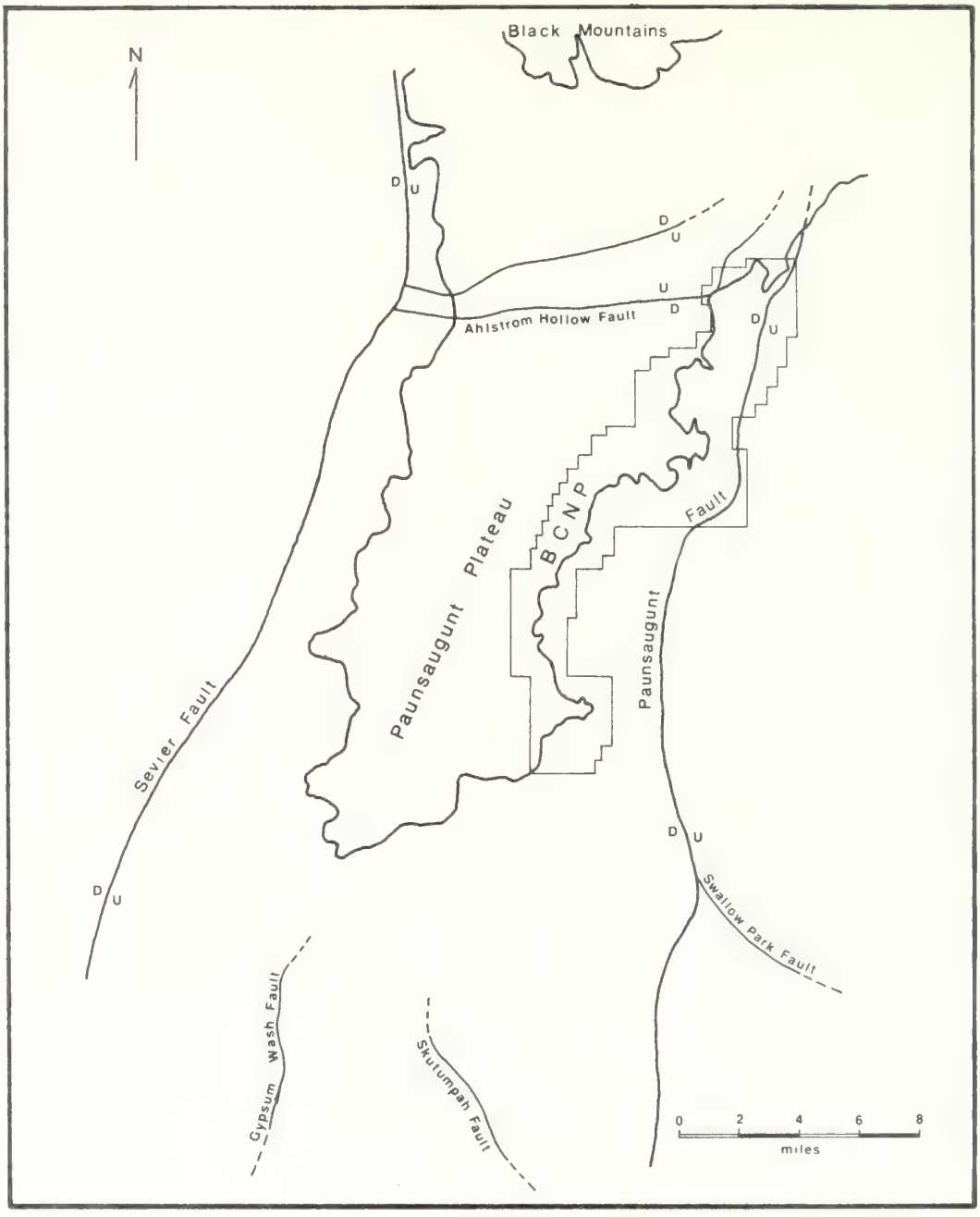

FIGURE 1. Bounding faults of the Paunsaugunt Plateau. After Gregory (1951).

montmorillonite was found.

The analysis of the sand, carbonate, and silt and clay fractions has not been completed so precise lithologies cannot be assigned to each bed, but they should fall into the general categories of argillaceous limestones or dolomites and calcareous or dolomitic siltstones and claystones. The beds, for the most part, are composed of a light calcareous matrix in which vermillion and ochre clasts of the same general composition are embedded giving the appearance of an intraformational conglomerate. The beds are massive, generally without shaly partings, and no fossils have been found in them.

WALL CLASSIFICATION SCHEME

The erosional forms (or hoodoos) in the Park are found both emanating from the main escarpment and farther out on the ridges extending fro the escarpment or on the ridges formed between lines of the drainage pattern. The best developed forms are mostly found along the main escar ment, particularly in the Silent City area, the Bryce Point area, and surrounding Boat Mesa. Different conditions and processes at work on these slopes produce forms which are capable of categorization into a small number of classes based on appearance and mode of origin.

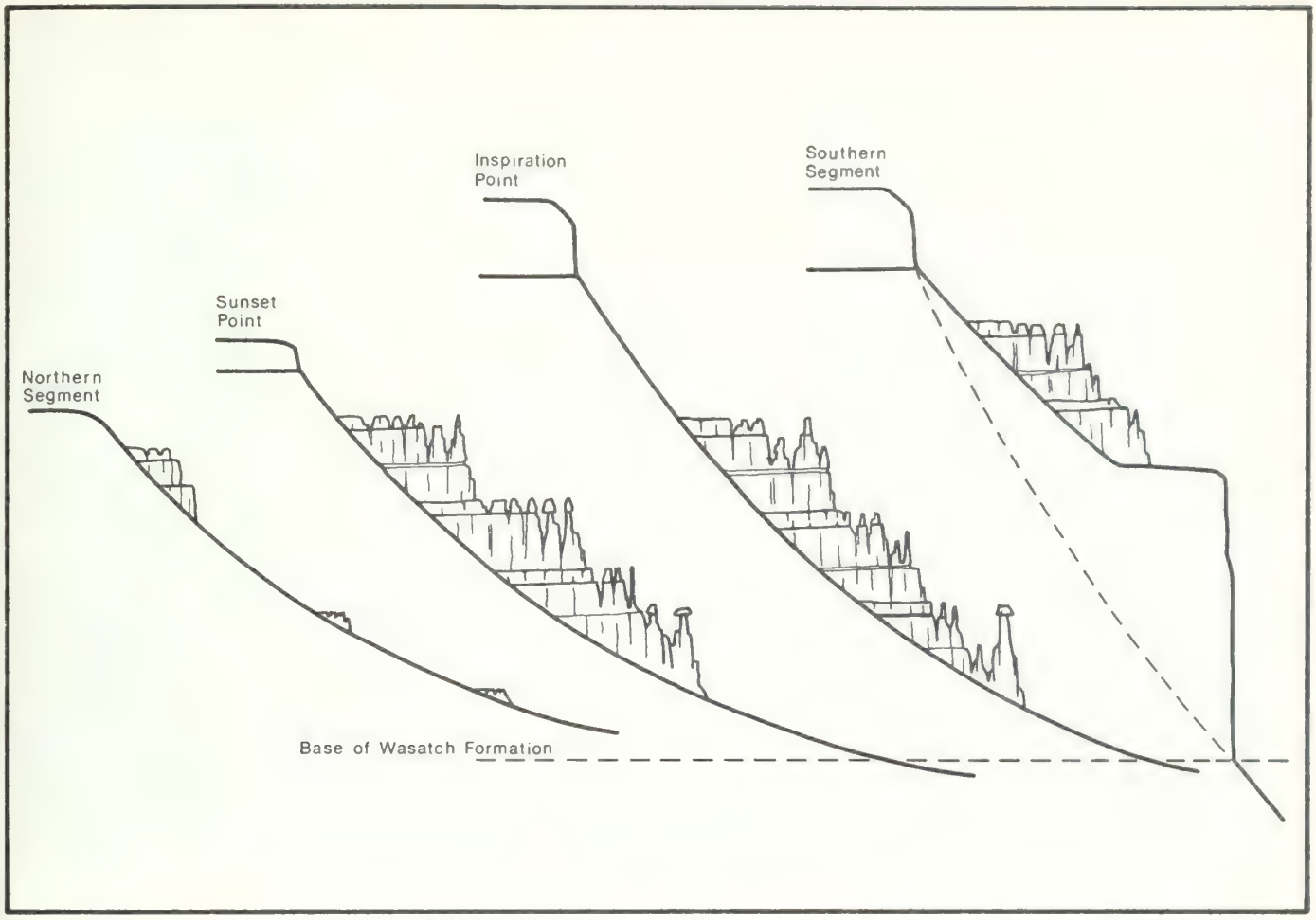

FIGURE 2. Diagrammatic representation of slope forms along the eastern escarpment.

1) Walls leading from the main escarpment and ridges which appear to result mainly from active downcutting in the gullies and/or differential weathering and erosion along the joints.

2) Secondary walls formed not directly on the rim or ridges, but on the main walls of class 1. These secondary walls have formed by weathering back along the joints in the main walls or by secondary gullying which began at an earlier stage in the development of the main wall.

3) Ridge crest walls which are formed on and follow the crests of ridges lower in the drainage basins and far removed from the main escarpment. These walls are the result of the exposure of one of the more resistant beds along the crest of the ridge combined with a rapid weathering at the base of the wall.

4) Ridge slope walls which may not have the distinctive slab form common to many walls along the main escarpment, but may be more rounded or irregular in shape. These walls are mainly found on the slopes of the lower ridges and on slopes with lower angles than those along the rim.

5) Possible residual forms found at lower elevations and on lesser slopes and whose mode of origin is uncertain.

SOME GENERAL CONDITIONS ON HOODOO FORMATION

Hoodoos do not occur exclusively along the rim. Numerous basins with dimensions on the order of hundreds or thousands of feet are found along the ridges on the interior of the plateau and in these basins hoodoos are formed. These basins were photographed from the air, several were visited on the ground, and one was selected as a study area (Figure 3).

These basins, along with the escarpment, have especially aided in the development of a number of conditions considered necessary for optimal wall formation. Certain features which are common to almost all of these basins have led to the development of the following criteria:

1) Slopes of southerly exposure or aspect--all of the basins are formed on the south facing slopes of the nearly east-west ridges where, due to the exposure, the vegetal cover is sparsest. Obviously, the lack of cover provides conditions under which gully formation can best occur. Other considerations involving exposure are the number of freeze-thaw cycles occurring on the slopes and the length

FIGURE 3. Hoodoos formed in a drainage basin on the south facing slope of a ridge on the interior of the plateau.

of time the slope is covered by an insulating blanket of snow.

2) Increased slope provided by the presence of a strong caprock or rapid downcutting at the base of the slope--most of the basinal outcrops headed at the top of a ridge where a thick resistant bed of limestone was present or only recently removed. This cap was not involved in hoodoo formation which began two beds lower on the slopes.

3) The presence of a critical range of slope values--where a strong cap was present on the ridge, the slopes in the basin gradually decreased laterally away from it. Where slopes of 50° or more were present, wall formation was generally poor or absent as it was also when the slopes became less than about 30°. Slopes on which the walls are best formed have been found to range from approximately 35° to 45°.

4) The presence of a less resistant bed between the ridge cap and the more resistant bed which forms the cap of the first level of walls--in the softer beds the gully development is stronger with a more regular spacing. The detritus concentrated in these gullies creates an intense cutting action on the more resistant beds.

RATES OF RIM AND SLOPE RETREAT

To obtain an estimate of the rates of rim and slope retreat without becoming involved in a long term study, a method was adopted using the amount of exposure of the root system of trees either on the rim break or on the upper slopes and coring them to determine their ages. Only well defined cases were used, that is, there was little or no curvature to the trunk and the original ground line could be determined within narrow limits.

A total of 60 trees provided usable data of ground loss and countable cores. The average vertical ground loss was found to be 4.4 mm/year (0.17 inches/year) or alternatively 292 years/meter (89 years/foot). The horizontal component the rate of rim recession, averaged 5.6 mm/year (0.22 inches/year) or alternatively 212 years/meter (65 years/foot).

SLOPE PROCESSES

Since gullying is the dominant process of scarp retreat over much of the escarpment (as well as being involved in hoodoo formation), measurements were undertaken to determine the types and rates of surface processes acting on the slopes.

The slopes formed on the softer beds have only a thin cover of weathering debris ranging up to 13 or 14 centimeters (about 5 inches) in depth but generally averaging less than 6 or 7 centi-

meters (about 3 inches). The surface is littered with centimeter size clasts from the more resistant beds and irregular clots composed of clays and carbonate. The profile quickly grades to millimeter size fragments of decayed bedrock and then to finely fractured bedrock at a depth of 7 to 10 centimeters.

Measurements were made on the softer beds where the gullies are either initiated or well formed. Grids of stones were set up on the slopes and the distances measured from two steel rods driven firmly into bedrock. The grids were set up at the beginning of the summer, measured at the end of the summer, and again at the beginning of the following summer. The measured downslope movement was very rapid, averaging 49 cm/year (1.6 feet/year).

The motion indicated by the grids was not uniformly distributed throughout the year, with no detectable motion occurring during the summer except for two stones caught in the path of a small rill which developed through one of the grids. The amount of movement and its temporal distribution indicates that freeze-thaw section is the dominant process producing the downslope movement on the slopes. The climatic characteristics of Bryce Canyon support this mechanism since there is an average of 200 freeze-thaw cycles per year based on a twenty year period of weather records.

The lack of movement during the summer leads to the conclusion that rainsplash and overland flow (which does not occur except during extreme rainfall) do not produce a coherent mass movement. However, some of the fines are undoubtedly selectively moved downslope by these processes without affecting the grids.

Summer rainfall does have a significant effect in the gullies, flushing the accumulated detritus, which has been delivered downslope by the freeze-thaw action, from the gully. The gullies are generally flushed clean to bedrock and the flow of detritus through them produces a very effective scouring action on the bedrock. Thus, these two seasonally alternating mechanisms, freeze-thaw action and flushing of the gullies by summer rainfall, combine to create an effective means of downslope transport of the weathering products and, at the same time, produce an intense cutting action in the gully bottoms.

MECHANISMS OF HOODOO FORMATION

Generally, the hoodoos are formed in conjunction with the retreat of the scarp which, except for the more resistant caps, occurs by headward erosion of the gullies. No evidence has been found to indicate any vertical etching by solution along the joints which might later lead to wall formation during or after exposure along the scarp.

The formation of the hoodoos has usually been attributed to differential weathering and erosion along the vertical joints which are prevalent throughout the Wasatch Formation. This mode of formation appears to have been justified on the basis of the effects of joints in other situations, and to my knowledge, by only one detailed study of the correlation between joint and wall trends in the main amphitheater section of the Park. While joints have been found to be involved in a number of cases of hoodoo formation and may also account for some of the directionality of the wall trends, they fail to explain a number of aspects of wall form or generation and are unsatisfactory as a unicausal explanation for the genesis of the hoodoos.

Two other processes, gully incision and differential weathering as a function of slope orientation, have also been found to contribute significantly to hoodoo formation. These processes are described in the following sections.

THE ROLE OF JOINTING

The joint pattern of the Wasatch Formation is extremely complex. The joints can be divided into two distinct sets, one vertical or near vertical, and a conjugate set with dips of approximately 30°. Studies concentrated on the vertical set since the others were less numerous and do not appear to significantly affect hoodoo formation. Studies by Brox (1961) and myself indicate that the vertical joints do not fall into simple distinct sets, but occur with strikes over a wide range of values although broad maxima do appear at certain values.

The lengths of the individual joints are extremely difficult to determine, but most appear to be a few hundred feet or less. The joint surfaces vary in smoothness with many joints being irregular or twisting. The jointing is also differential in nature due to the varying competency of the individual beds, with the thinner, purer carbonate and sandstone beds tending to have the highest joint density.

The relationship of the joint strikes and wall trends has been examined in only one study (Brox 1961). In this study, strikes of approximately 80 prominent joints were measured in the main amphitheater section of the Park and plotted on a rose diagram. A similar diagram was prepared for the trends of approximately 120 ridges and walls from enlarged aerial photographs of the same area. Comparison of the diagrams shows a degree of correlation, but no correlation coefficients are given.

Rather than using this statistical approach, a more direct approach was taken. A section of rim approximately 800 feet long containing 10 major walls was selected for study. The walls and rim of this segment were mapped and then the strikes of the accessible joints cutting the walls were measured and plotted on this map. The resulting configuration of walls and joints is shown in Figure 4. From this map one can see that the outline and configuration of the walls does not generally coincide with the dominant joint trends except where the walls and joints are both orthogonal to the rim. The distribution of the joint strikes is shown in Figure 5. In the east-west direction there is a very pronounced absence of joints, yet the trend of many of the walls along this segment is to the east.

The foregoing discussion is not intended to imply that the joints have no effect at all. A number of cases have been found where deep recesses have formed along joints. However, other recesses have been found cutting across joints at only slight angles with no apparent deflection. In still other cases, gullies, in which there is no evidence of jointing, have been found paralleling very prominent joints only a few feet away. The conclusion drawn is that while large scale jointing may play a role when favorably oriented in a direction approximating the wall trend, it cannot be considered as the only mechanism by which the hoodoos are generated.

Jointing may also have an effect when found on a micro-scale, producing a differentially fractured zone of higher fracture density in the more resistant beds. Some observations have been made along the rim and in a road cut near the Bryce Point parking area. The road cut was made in

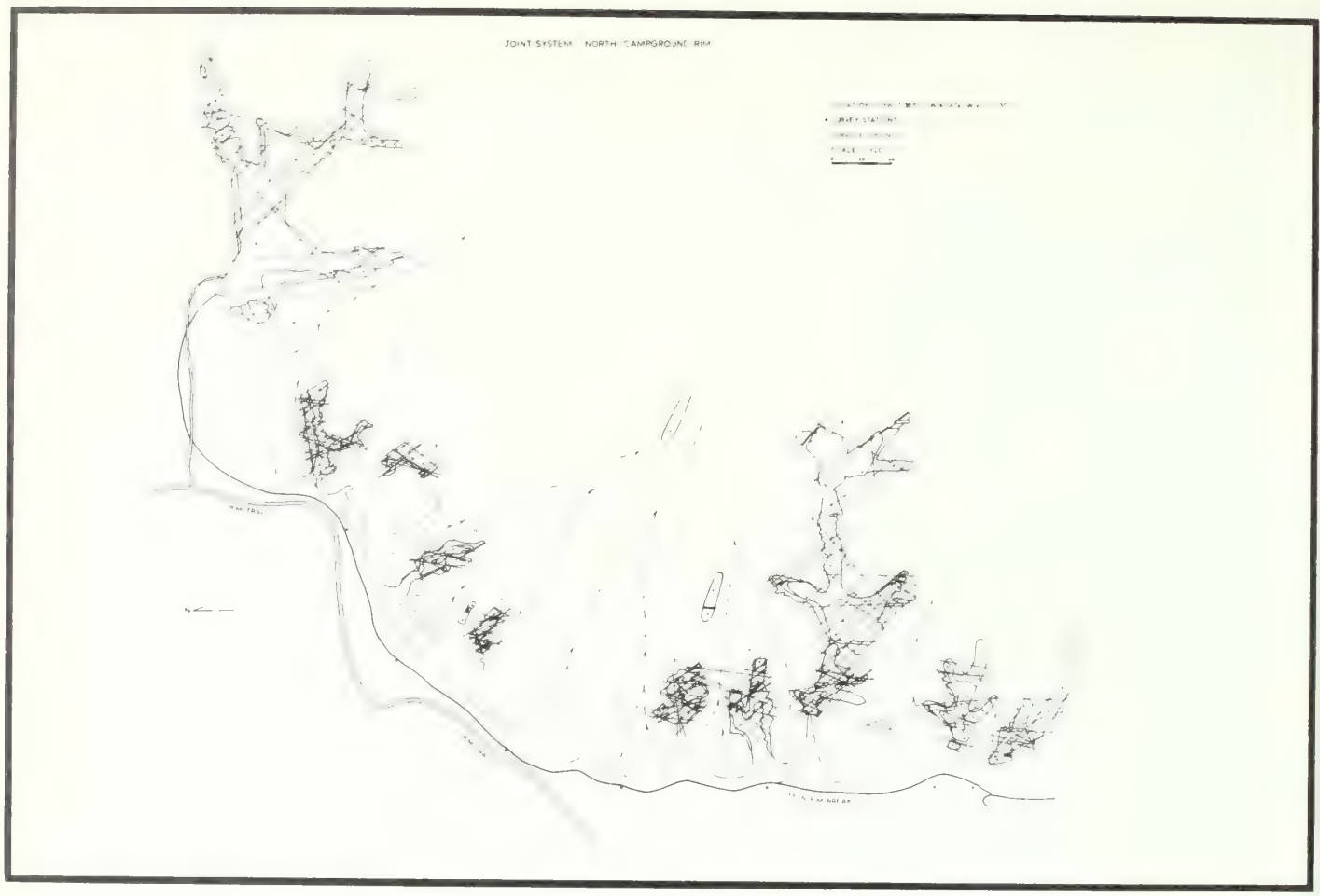

FIGURE 4. Configuration of walls and joints along the North Campground rim.

about 1930 and gullies and intervening ridges have already formed on it. Incipient gullies appear to be forming where there is a higher density of fractures in the more resistant beds, while the inter-gully ridges are found in the zones of lesser density. In this way the joint pattern may control the position of the gullies and ridges but not the course since the fracture pattern found in the more resistant beds usually does not continue into the softer, less competent underlying beds.

THE ROLE OF GULLYING

Along much of the rim the dominant mode of scarp retreat is headward erosion of the gullies. Where gullying is initiated at the head of the scarp, small drainage basins are formed with from one to eight first order gullies. Several longitudinal profiles measured in the gullies of these basins have a hydraulic profile which can be described by an exponential function. Along the segments where no strong resistant beds are found, the joints appear to exert little, if any, control over the location or courses of the gullies. In segments of the rim where more strongly resistant beds are found, gully position may be controlled by zones of higher fracture density in the more resistant beds as described in the last section.

In passing through one or more of the resistant beds, the gully is "pinned" in position and any tendency toward lateral migration is greatly reduced. The ridges leading to the walls and the walls themselves divide the basins into independent units. As the headward erosion continues, the major ridges, as well as the smaller inter-gully ridges, are maintained and where no resistant beds exist to form a cap, the scarp continues to retreat in this form. However, where sufficiently resistant beds capable of forming a cap exist, the inter-gully ridges may persist and a wall begins to form. With continued headward erosion of the gullies, and protected by the cap, the wall is continuously carved out of the scarp. This process may follow favorably oriented joints where available, but it is not dependent on their presence.

Secondary walls or fins may also be formed on, but at an angle to, the main wall by a similar process involving cross-grading on the main gully slopes. In this process, the joints may play a more active role since more of the resistant beds are exposed on the gully slopes and the initiatir gullies do not have the length and depth of those originating directly on the scarp.

THE ROLE OF DIFFERENTIAL WEATHERING

The relative rates of weathering for the softer beds are strongly dependent on the orientatior of the surface. While very rapid rates of ground loss occur on the generally prevailing slopes (usually around 40° to 45°), the rates for the vertical or near vertical cap protected surfaces are significantly less. Several photographs taken in 1929 were found in the Park files and were retaken this summer from the same vantage

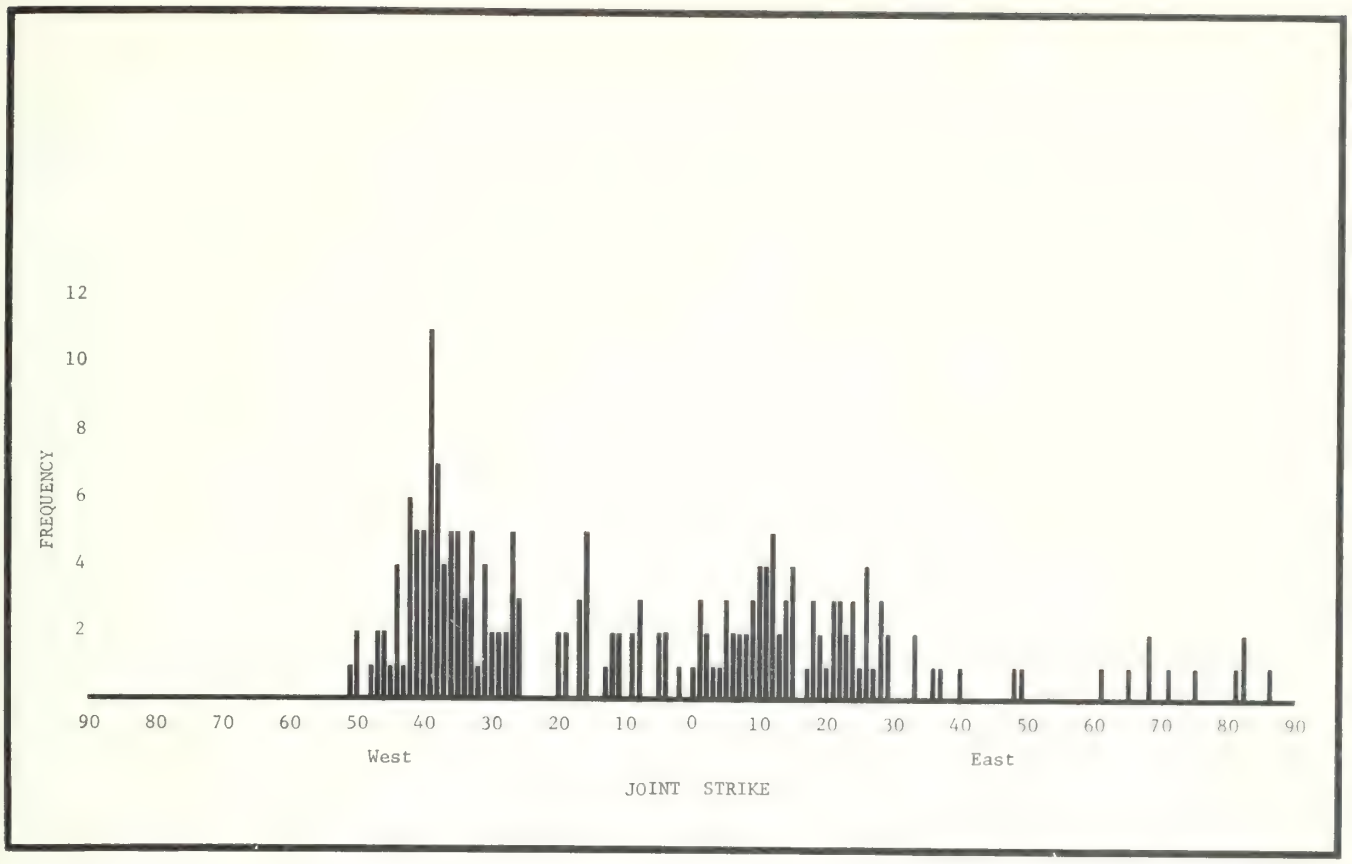

FIGURE 5. Frequency distribution of the joints cutting the walls along the North Campground rim.

points and approximately the same time of day. Some of these photographs contained views which included wall surfaces in the foreground or middle ground. Enlargements were made from both sets to the same scale and compared.

Close examination of the wall surfaces revealed only minor changes during the 47 year period between the photographs. The most obvious changes involved the loss of a few small fragments from various positions on the walls and a very slight general backwasting which could be seen in the reduction in relief of some of the micro-scale features. A very crude estimate based on this reduction in relief places the rate of backwasting on the order of a quarter inch during this period or approximately 13 cm/1000 years.

At the base of the walls there is both a very sharp break in slope and a weathering boundary. Very little talus accumulates at this break. On the vertical surface a few inches above the break, the usual condition consists either of a coated surface or a weathering rind rather than a weathered zone of any significant depth. On the slope immediately below the break, a weathered zone of variable depth (5 to 15 cm) depending on the softness of the bed, is developed. Trenching at the base of the walls shows that the bedrock of the wall makes a rapid transition from the vertical surface to an inclined surface paralleling the slope leading from the wall. The occurrence of this weathering zone does not depend on the presence of joints and is found at the bases of most of the walls with the exception of those immediately adjacent to gullies.

With this weathering process in operation, a vertical surface formed with a protective cap to maintain the wall surface will tend to rapidly propagate itself downward. If the rate of ground loss measured along the escarpment also applies to the slopes at the base of the walls, then the horizontal and vertical rates are, respectively 43 and 34 times the rate of backwasting on the walls. For every unit distance which the wall retreats, the base will have been extended downward by 34 units.

The extremely low rate of retreat of the wall surfaces relative to the slopes is a consequence of several factors. For the combination of lithology and climate, chemical weathering processes play a less significant role than mechanical processes. The bedrock of the walls is not highly fractured in most beds and, in conjunction with the drainage on the vertical surface, freeze-thaw action cannot operate effectively. Also, over much of the wall surface a protective coating of carbonate and clay, similar to a stucco or slip glaze, is formed by rainwash. At times this coating becomes thick enough to form beautiful tapestries of dripstone. This coating forms both a cement which tightly bonds fractured bedrock into place and a relatively impermeable surface which prevents entry of water into the fractures. It is this coating which gives many of the walls their rather uniform characteristic reddish-tan color rather than the more variegated coloration of the bedrock.

This process depending on the differential rates on the vertical and inclined surfaces

appears to be the most general process at work in wall formation and explains the origin of the ridge crest and ridge slope walls where no other mechanism could be invoked, that is, no suitable joints were present and no direct gullying action was involved.

FAULTING

Other than the faults shown in Figure 1, no other faults have been reported within the Park boundaries. During the field work, five faults have been discovered in the Park. Four of these faults are located in the main amphitheater section. The faults have vertical displacements ranging from 6 meters (20 feet) to 29 meters (95 feet) and, with the exception of a reverse fault with a dip of approximately 60° east of Bryce Point, are vertical faults. Of the faults in the main amphitheater, two have very little topographic expression, while the other two produce deep recesses to the east and west of Bryce Point. While the faults appear to have affected rim development and outline, the effect on hoodoo formation is uncertain since in some areas hoodoos form immediately adjacent to the faults or even extend across the fault, while in other areas hoodoo formation has been suppressed, possibly due to the greater fracturing of the bedrock.

CONCLUSION

The genesis of the hoodoos is a unique result of the combination of circumstances found in the region of the Paunsaugunt Plateau. Under the given circumstances, much of the problem of hoodoo formation reduces to one of the types and relative rates of the weathering, mass-wasting, and erosional processes acting on the escarpment. That this is the case is shown by the sets of conditions under which the hoodoos will form. Considering these conditions, the active retreat of the scarp by gullying and the occurrence of the hoodoos in situations which cannot be accounted for by jointing, the origin of the hoodoos solely as a function of the jointing does not seem tenable. However, when combined with the gullying and differential rates of weathering based on orientation, the full range of erosional forms and their location becomes much better understood.

LITERATURE CITED

BROX, G. S. 1961. The geology and erosional development of northern Bryce Canyon National Park. Unpublished thesis, 70p.

GREGORY, H. E. 1951. The geology and geography of the Paunsaugunt region, Utah. U. S. Geol. Survey Prof. Paper 226.

HOLOCENE AND PLEISTOCENE LAKES IN ZION NATIONAL PARK, UTAH

Wayne L. Hamilton[1]

INTRODUCTION

Zion National Park is located in a semi-arid region which is undergoing rapid erosion, on the order of 25 cm per 10^3 years regional downcutting. The terrain is dominated by stream-cut canyons, hence it is not at first apparent that lakes, or the sediments of Quaternary lakes, would be found there.

However, three ephemeral lakes currently exist in the Park. One, only a few years old, is in Mystery Canyon near the famous Zion Narrows. Another, which to my knowledge has never been visited, is nestled in upper Beartrap Canyon. The third, here called Beatty Lake, is near the mouth of the canyon of the South Fork of Taylor Creek. Mystery and Beatty lakes (and probably Beartrap Lake) are "slide" lakes, produced when rockfall blocked the respective canyons. They are each only a few hectares in size. Locations are shown in Figure 1.

Moreover, the deposits of much larger Holocene lakes have been recognized by Grater (1945) and Eardley (1966). The largest of these, whose deposits are most accessible and apparent, was Sentinal Lake, which occupied Zion Canyon between the Court of the Patriarchs and Angel Landing.

The lake deposits crossed by the park road in the lower canyon of the South Fork of Taylor Creek (downstream from Beatty Lake) are somewhat younger. This lake will be referred to here as Paria Lake, named after Paria Point nearby.

A still-younger Holocene lake partly filled an area of 1.2 square kilometers in Hop Valley with sediments which have been only slightly incised. Eardley (1966) collected wood 5 meters from the top of this section, which was dated at 670 ±200 years B.P. (W-1742).

Sediments of other possibly Holocene lakes have been briefly visited by the writer in the headwaters of Currant, Cane, and Smith creeks southwest of Burnt Mountain. The sections have been neatly incised, but large amounts of sediment remain, consisting of alternating sand and organic-rich clays with much promise for interpretation. A fossil radius-ulna of a bighorn sheep, snails, and abundant wood have been collected.

These Holocene lakes were also "slide" lakes. Hop Valley Lake was produced by a sudden rockfall from the north end of the west wall of Hop Valley. Blowholes are still visible in that slide mass, attesting to the escape of entrapped air. The Currant, Cane, and Smith creek lakes were apparently caused by mudslides.

Finally, it is the main purpose here to report that extensive deposits have been found marking the existence of at least two Pleistocene lakes in Zion. Coalpits Lake was formed when lava flowed from a volcanic vent associated with Crater Hill volcano (Neilson 1976), damming ancestral Coalpits Wash. This lake may have had several stages of development in response to subsequent eruptions.

Other lake sediments in the lower canyon of the Right Fork of North Creek (the so-called Great West Canyon), at Trail Canyon, appear to be related by elevation to erosional outliers of basalt that flooded the lower canyon of the Left Fork of North Creek and dammed the Right Fork at the confluence. The flows were derived from volcanic vents in Cave Valley. Trail Canyon Lake probably had two stages; a later high stand being the result of a slump which blocked the canyon of the Right Fork.

DISCUSSION

Existing Lakes

Mystery Lake is believed to have formed within the past few decades (at least prior to 1973) behind a dam of white Navajo Sandstone rubble derived from spalling of the north wall of Mystery Canyon. The rockfall produced an arch which is visible from the upper switchback of the West Rim Trail. This lake is accessible only by technical rockclimbing. Its level fluctuates widely and rapidly depending on precipitation, and because the dam is highly permeable to water. The sediments consist of sand and fine gray mud derived respectively from the Navajo and Carmel formations. Reference marks were engraved on the vertical walls of the lakeshore in 1975, making it possible to determine the rate of sedimentary infilling. In time the rate of regional downcutting can be calculated for that watershed.

Beatty Lake is nestled between Paria Point and Beatty Point at the mouth of the canyon of the South Fork of Taylor Creek, one of the finger canyons in the northwest corner of the Park. The dam consists of slide material derived from high on the north wall of Beatty Point and looks almost like a terminal moraine. It is believed that the dam is of the order of a thousand years old, because no scar is visible on the canyon wall to mark its origin.

Hevly (this volume) and co-workers and the writer took core samples from the bed of the lake, and Hevly's report on the microfossils in the upper sediments is presented elsewhere here. According to Hevly the upper 130 cm consist of reddish-brown clay with a lesser amount of sand at the lower end of the core. There are dark organic horizons within the clay, having an average spacing of about 18 cm. Most dark layers are less than a centimeter in thickness excepting the lower one, which is about 18 cm thick. Based on observations that the lake is partially filled with water during spring snowmelt season and dry in summer and fall it is reasonable to consider these layers as the equivalent of varves. A count of such "varves" may tend to overestimate the age of the lake, however, because infrequent heavy rains in that watershed would also leave a deposit of sediment. In addition to the pollen work now being conducted on these sediments, a continued coring effort seems worthwhile in that it may provide a record of spring runoff as well as a value for the rate of regional downcutting there.

Beatty Lake is now nearly brimfull with perhaps 23 meters of sediment, and the dam is being breached on the north side. It may be prudent to watch that drainage during spring snowmelt season

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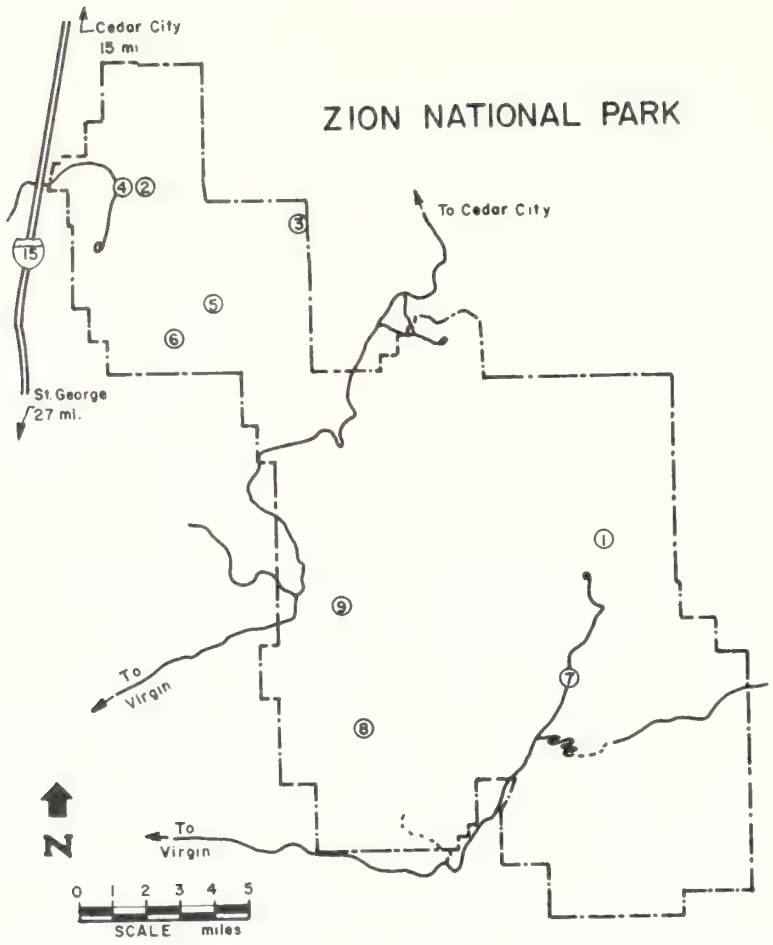

FIGURE 1. Map of Zion National Park, showing park roads and locations of existing lakes and sediments of Holocene and Pleistocene lakes. Numbers correspond to the following lakes: 1, Mystery; 2, Beatty; 3, Beartrap; 4, Paria; 5, Hop Valley; 6, Current Creek; 7, Sentinal; 8, Coalpits; and 9, Trail Canyon.

in the event that final breaching might pose some threat to the park road downstream.

Holocene Lakes

Representative sections of Sentinal Lake are given in Figure 2. This lake was produced by damming when a large slump block moved away from the Sentinal in Zion Canyon, blocking the Virgin River. According to Grater (1945) "It was caused by an extensive fracture and joint system, water-saturated shale beds underlying the massive Navajo Sandstone, and regional dip of 1^{o}-3^{o} to the northeast." Grater's analysis of the rate of erosion of the slide debris since the dam was breached led him to state that ". . . at most only a few thousand years can have elapsed since the slide occurred."

Plant carbon collected from pink silts in the thick-bedded sand about 5-meters above and conformably overlying thick gray lake clays in a dry fork of Birch Creek gave a radiocarbon age of 3600 ±400 years B.P. (W-3371). It appears that the dated horizon is in a shallow water delta sequence or an alluvial fan deposit of Birch Creek. A sequence of at least 6.5 meters more sand, with some silt and gravel, overlies the dated silt. It is likely that the dated silt slightly postdates the time of breaching of the dam, because it is underlain by crossbedded sand. The abrupt change from gray clay to alternating sand, silt and clay suggests lowering of lake level, reworking and redeposition of shore deposits with repeated temporary blockage of the spillway by small slides.

A profile of the North Fork of the Virgin at Birch Creek suggests that the present grade rests on about 30-meters of lake deposits, and a field survey puts the top of the thick gray clay at about 22-meters above the river. Thus the Virgin River has cut through about half the original thickness of the lake clay beds.

A calculation based on present discharge (water and sediment discharge measured respectively at Park Headquarters and La Verkin, USGS 1974), using appropriate assumptions, suggests that the clay sediments in Sentinal Lake were deposited over an interval of about 730 years. Alternatively, the average "varve" thickness is about 12 cm at Birch Creek, giving a deposition interval of about 440 years for the clay. It is assumed that the silt and sand underlying the dated horizon were laid down in a very short time, perhaps about a decade. In this way the date of the slide is tentatively placed at 4200 B.P. with a combined dating and calculating error of ±550 years.

The upper clay and silt sediments have been somewhat productive of mollusks in two locations (at about 4300 feet elevation). Species identified are *Discus cronkhitei* (16 individuals), *Succinea avara* (6), *Gyraulus parvus* (6), *D. shimeka cockerelli* (2), *Microphysula ingersolli* (2), *Physa virgata* (2), *Euconulus fulvus alaskensis* (1), and *Musculium partumeium* (1 valve).

I gratefully acknowledge the help of Jerry Landye and Alice Lindahl in verifying and correcting these and other identifications to follow.

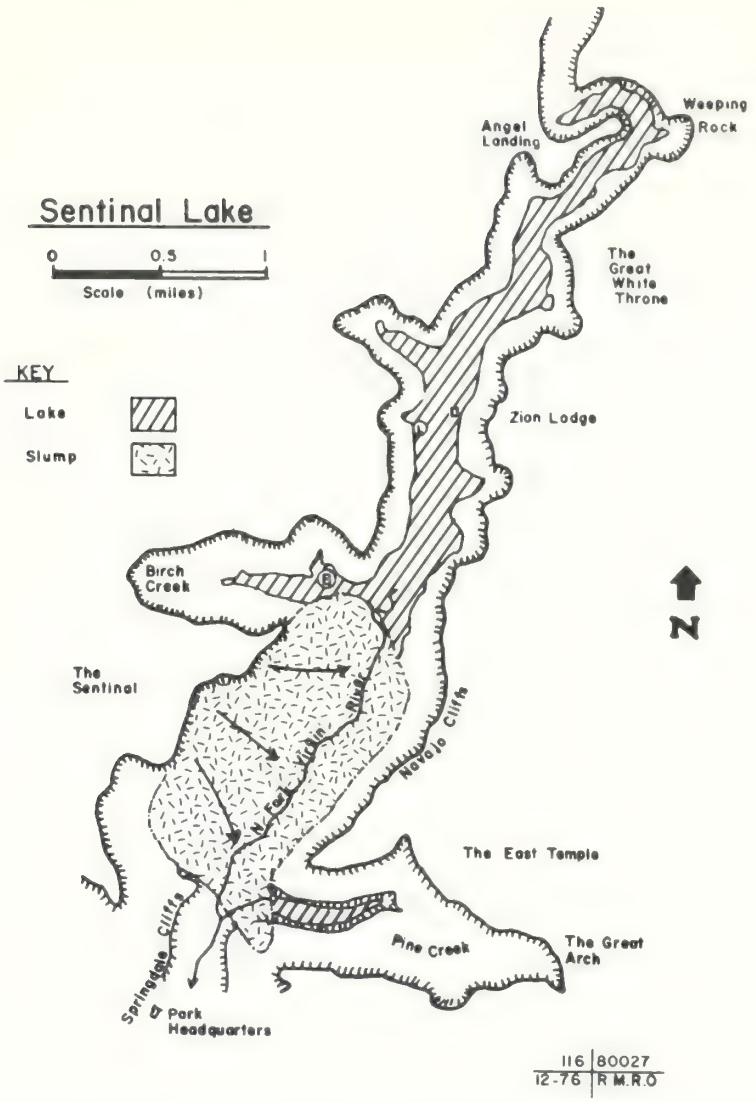

FIGURE 2(a). Map of Zion Canyon, showing outline of Sentinal Lake (and Pine Creek Lake), the toreva-block slump and slide mass that blocked the canyon, and locations of measured sections near Birch Creek (B) and near the Lodge (L).

Sentinal Lake probably occupied an area of about 1.2 km^2 and existed as a somewhat deep lake for several centuries. Hence, it is anticipated that it may yield more diverse fossil materials, and it may prove interesting to search the shoreline for human artifacts.

The Sentinal slump also blocked the mouth of Pine Creek canyon. Lacustrine marls and silts from Pine Creek Lake are preserved only in a small cave about 100 m south of the Pine Creek highway bridge.

Representative sections of Paria Lake are given in Figure 3. The slide that dammed this drainage moved down the south wall of the valley, blocking the water gap formed by the Springdale sandstone member of the Moenave Formation. The sediments, consisting mainly of sand with some silt and lesser amounts of clay, are characteristic of a ponding situation which ultimately stretched upstream about 1000 m above the dam and covered about 0.1 km^2 with up to 13-meters of deposits.

Three pine stumps (identified by Robinson, pers. comm.) in growth position have been exhumed by subsequent stream dissection a few hundred meters downstream from the road crossing, at and slightly above present stream grade. It is believed that these trees were inundated and killed a short time after the stream was dammed. One tree has been radiocarbon dated at 3610 ±300 years B.P. (W-3618).

A. J. Eardley (1966) cited a radiocarbon date of 2800 ±200 years B.P. (W-1746) on lignitic wood collected ". . .about 10 feet below the top of the fill . . ." near this cross section. These age data permit calculation of the rate of regional downcutting in the watershed. Assuming a pyramidal basin (most canyons are v-shaped) a value of 24 x 10^{-3} cm yr^{-1} is obtained. This can be compared with 16 x 10^{-3} cm yr^{-1} for the Colorado River watershed (Judson and Ritter 1964).

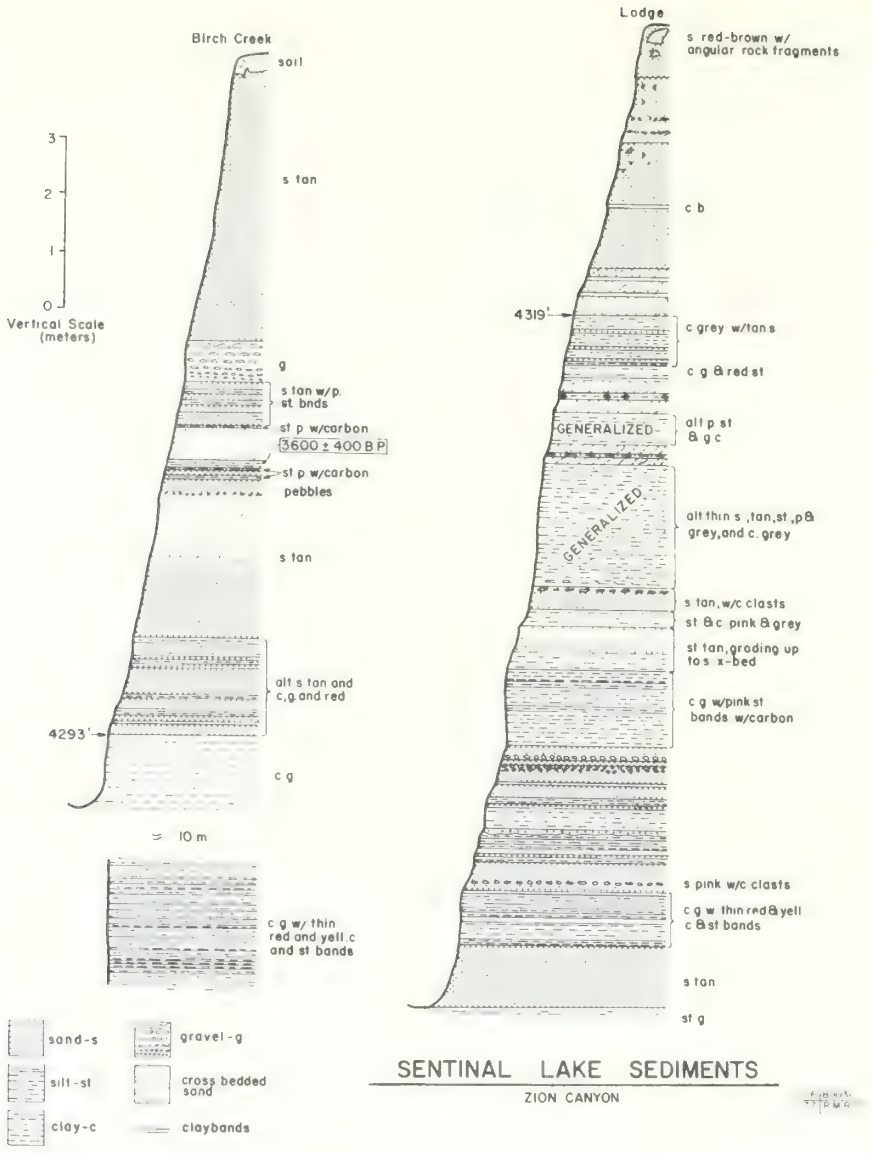

FIGURE 2(b). Cross sections of Sentinal Lake sediments measured near the Lodge and at Birch Creek. Dated pink silt (st. p.) postdates deposition of grey clay (c.g.) at Birch Creek.

The average spacing of black claybands in sand at measured section A was less than 20 cm. This value is comparable with the spacing of "varves" in the Beatty Lake core.

Mollusks were abundant in marl strata at and near measured section B, elevation 5850 feet. Species identified are *Succinea avara* (95 individuals), *Discus cronkhitei* (51), *D. shimeki cockerelli* (21), *Vallonia perspectiva* (13), *Euconulus fulvus alaskensis* (11), *Oreohelix strigosa* (1), *Cochlicopa (Cionella) lubrica* (1), and *Physa* sp. (1).

A radius-ulna of a bighorn was found on the surface beside the westernmost pine stump, however it may be intrusive.

Pleistocene Lakes

Representative sections of Lake Coalpits sediments are illustrated in Figure 4. The earliest lake deposits so far found are at the bottom of section III, a few hundred meters west of the point where the Petrified Forest trail crosses Coalpits Wash. There, lake sediments consisting of alternating thin pink limestone and sand overlie tephra and lap onto weathered basalt talus southwestward. It is significant also that Navajo sandstone boulders are present in the lowest tephra, increasingly toward the east.

Field relations, and the degree of weathering of the lowest tephra in relation to other tephras in the area situated above the highest lake level (about 4400 feet), suggest that the lowest tephra was deposited in lakewater and that the lake was produced by lava damming. The Navajo sandstone boulders in the tephra, and increasing amounts of calcite-cemented Navajo slide debris toward the east and up to 20 m lower than the lowest sediments, show that a large mesa on the southeast shore of the lake slumped into the lake basin at about the time of damming. Whether it was toppled by earthquakes associated with the eruption or by the elevated watertable caused by the lake is uncertain. It is believed unlikely that the slump was responsible for damming the drainage, however, because Nielson's (1976) evaluation of the sequence of flows from Crater Hill

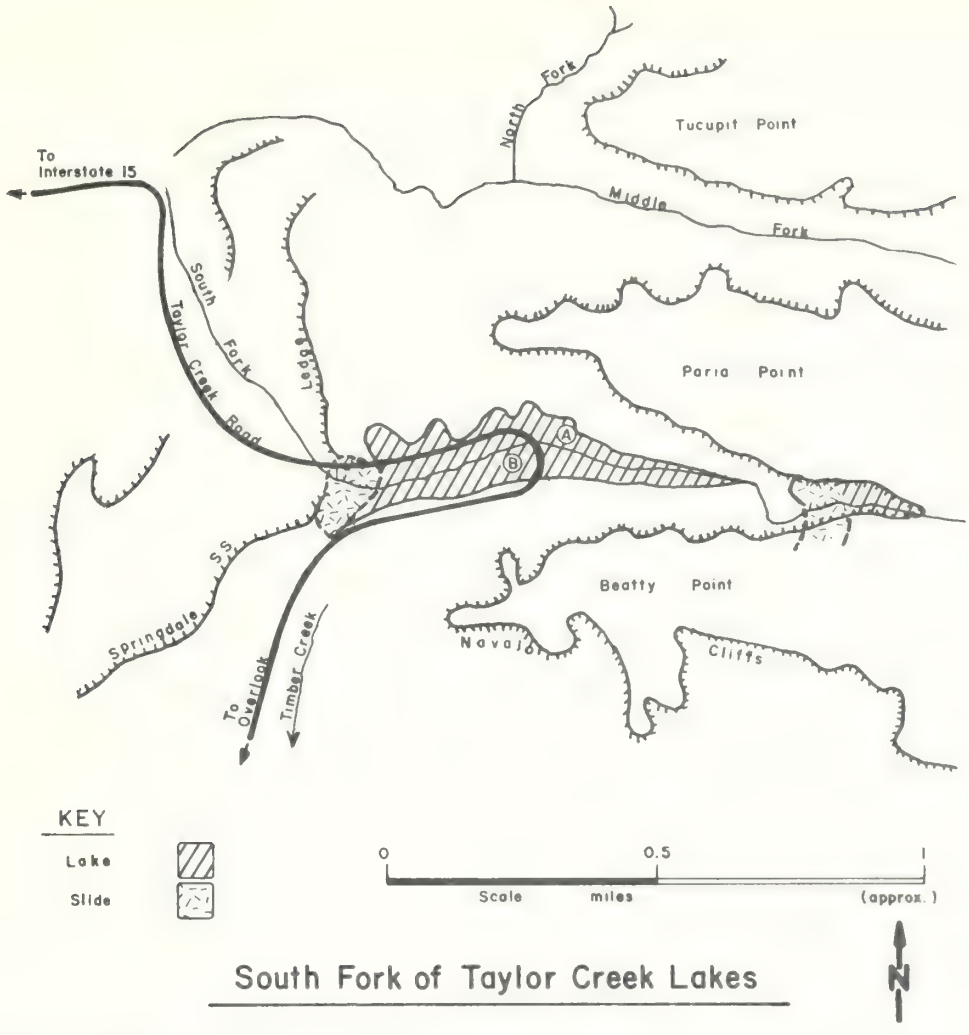

FIGURE 3(a). Map, showing location of Paria Lake and Beatty Lake, the former being in the center of the map. Also shown are the slide and rockfall masses that formed the dams, locations of measured sections, and the park road to the finger canyons overlook.

vents shows that Coalpits Wash has been relocated eastward in response to flow damming.

The tephra was probably the source of the lime that cemented the slump rubble and pink silts in the lowest part of the section. These thin limestones contain abundant trackways in an excellent state of preservation. Most seem to be tracks of insects, tentatively identified as those of an ant, a beetle, a horsehair worm, and an aquatic insect larva (see Figure 5). One track is probably that of a camel (identified by E. H. Colbert), and another is of a large bird, probably a raptor.

The limestone also bears the impressions of two aquatic plants; *Azolla* sp. (Mosquito fern) and a long-leafed pondweed resembling *Potamogeton*. Several slabs exhibit oscillation ripple marks, and others bear mud crack and raindrop impressions. Burrows of mollusks are common, and one impression of a mussel was found.

In cross section IV (Figure 4) the upper conglomerate limestone at the top of the track sequence is deformed, with fold axes sub-parallel to the long axis of the lake (striking N. 35° E.). It is believed that the deformation occurred following rapid deposition of the overlying tephra and sand. It appears that an eruption of Crater Hill may have contributed to the marked change in rate and type of sedimentary accumulation. Whether this represents a breaching event (where an infusion of tephra and lava led to erosion of the upper lake basin, supplying increased sediment load in the lower part), or formation of a higher lava dam at the lake outlet, is not known at this time. The change in state of preservation of fossils at this horizon suggests the possibility of a sizeable lacuna. Nielson (1976) recognizes a sequence of four flows, so the lake probably had a complex history.

Near the top of cross section IV is a clay horizon, about 20 cm thick, which has yielded the best preserved mollusks from Lake Coalpits: *Gyraulus parvus* (52 individuals), *Succinea avara* (3), and fragments of *Stagnicola*. This horizon correlates very closely with the bottom of cross section II, where the following species are represented in a thicker clay stratum: *Pisidium* sp. (5 valves), *Helisoma* sp. (?)(3, plus fragments), *Gyraulus parvus* (2), *Stagnicola* (2), and *Succinea avara* (1).

Above the mollusk horizon at cross section II are alternating thin clays and crossbedded sands. These units suggest that the lake was frequently "dry" enough so that small intermittent streams formed on the lakebed. The clays here can be traced for about half a mile to the northeast, indicating that a rather sizeable body of water

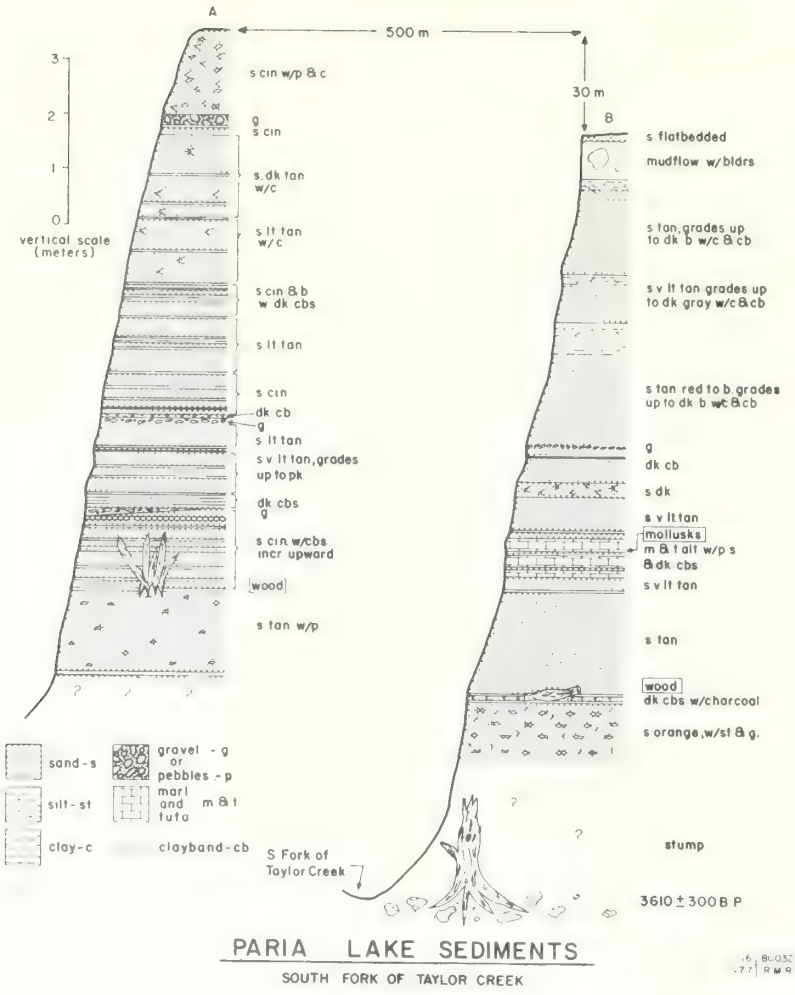

FIGURE 3(b). Cross sections of Paria Lake deposits measured where the park road crosses the South Fork of Taylor Creek. Section A consists mainly of alternating sands and thin carbonaceous clays. Symbol < signifies carbon (c); sand (s); marl (m); tufa (t); gravel (g); pebbles (p); clay band (cb); pink (p); brown (b); cinnamon (cin).

formed at times. Moreover, the units are thicker than those in Paria Lake and roughly comparable to those near the top of the Sentinal Lake section. Therefore, I am inclined to believe that there was a much greater annual discharge in the Coalpits watershed at the time of Lake Coalpits than at the the present.

The Pleistocene age of this lake is inferred from the fossil camel track and from a calculated age of the youngest Crater Hill flows. The calculation was based on Best's potassium-argon date (pers. comm.) on a nearby unrelated flow which permitted an estimate of the rate of downcutting in Dalton Wash, adjacent to Crater Hill.

The preservation of these lake sediments is due almost entirely to the fact that the present course of Coalpits Wash has developed in the slump and slide debris southeast of the lakebed. Lake deposits that presumably also filled Scoggins Wash nearby have been removed by erosion. Though much of the alluvial fill in the lower main canyon of the Virgin River, for example near Grafton, can probably be attributed to an interval of lava damming, lacustrine sediments are scarce.

Representative cross sections of Trail Canyon Lake sediments are given in Figure 6. At section A slide debris overlying Chinle bedrock shows that the original course of the Right Fork of North Creek was about 300 m north of the present channel at Trail Canyon. This slide material can be traced south to the slopes of Cougar Mountain.

The upper lake sediments in cross sections A, B, and C and elsewhere form a prominent "terrace" along the north side of the Right Fork canyon, suggesting a relatively long stand of lake level at that elevation (4600 feet). This level corresponds to the elevation of an outlier of basalt on the Springdale ledge near the confluence with the Left Fork, which was flooded with Pleistocene lava from vents in Cave Valley. This is the principal evidence for lava damming, hence a Pleistocene age, and it must be considered in question until better evidence is found.

Field observations support the view that the Cougar Mountain slide was not thick enough to have dammed the Right Fork for an extended interval at the 4600 foot level, though it or a subsequent slide did apparently fill the canyon where the pre-existing canyon is indicated in Figure 6a. A later slump dam, described below, was apparently breached before appreciable deposition could occur.

The section at site C is roughly 50 m thick, but there has been time to measure only the upper half. It is thought reasonable to view

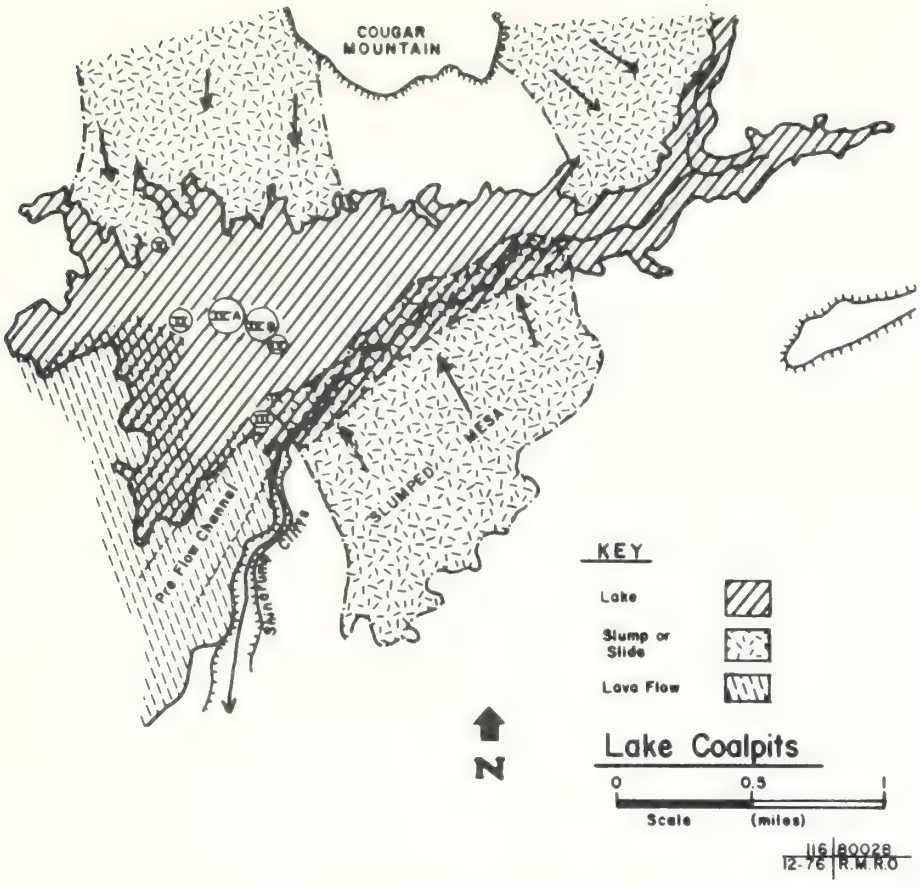

FIGURE 4(a). Map of Coalpits Wash, showing approximate outline of Lake Coalpits, basalt flows from Crater Hill, pre-flow wash channel, locations, of measured sections, and slump and slide deposits. The mesa slumped into the lake basin at about the time of initial lava damming. Slides from Cougar Mountain occurred later.

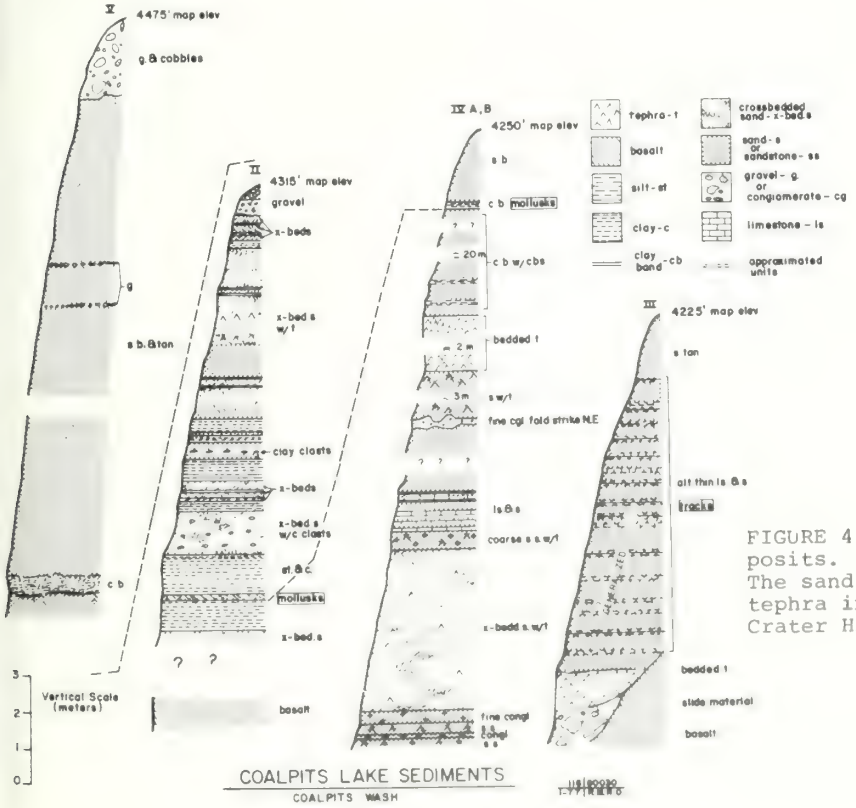

FIGURE 4(b). Cross section of Lake Coalpits deposits. Lower sediments rest on basalt and tephra. The sand and clay sequence begins above the upper tephra in section IV. At least two eruptions of Crater Hill see to be recorded here.

FIGURE 5. Tracks formed as lake muds were exposed to air on seasonal lowering of lake level. Preserved in pink limestones in lower part of Coalpits section III. Square in each photo measures 1 cm on a side. (top) Insect tracks tentatively identified as an ant (tiny erratic marks above center), a beetle (large check-shaped marks), and an aquatic insect larva (zig-zag in lower left) (center) A large bird, possibly a raptor like an eagle. (bottom) Camel.

the thin alternating clay and sand units as annual events and the thick sands (including pebbles) as derived from heavy local precipitation. The clay clast horizon in the lower third of the section may represent a brief episode of breaching.

Mollusks, found only in one clay unit in section B, are poorly preserved (due to crushing). Species represented are: *Gyraulus parvus* (17 specimens), *Succinea avara* (6), and *Planorbella tenuis* (1, and many fragments). At the horizon of the coarse gravel near the top of section B, skeletal remains were found on the surface. These included a thoracic vertebra (identified as probably bison by C. T. Williams, pers. comm.) and a fish vertebra.

A high stage of Trail Canyon Lake is indicated by a sand-capped bench developed on a large slump block on the north wall of the canyon. The block moved down from the face of an unnamed mesa to the north, and its lowest part now lies at about 4825 feet elevation. The coarse gravel near the top of cross section B was probably derived from the slump debris. The paucity of deposits overlying the coarse gravel and slump debris is taken as an indication that the high stage was of short duration.

It is believed likely that the northern slump as well as the Cougar Mountain slide, and other slides preserved on the canyon walls farther upstream, were promoted by the elevated water table that existed during the time of the lake. Moreover, many of these slide masses (also in the Coalpits drainage and in Zion Canyon near Springdale) seem to owe their preservation to partial cementation which is another manifestation of an elevated water table, or perhaps a moister climate.

CLIMATIC INFERENCES

The sedimentary and macrofossil record can be used to reconstruct some parameters of climate in the area. Such conclusions should be viewed as suggestive only, and in a second analysis must be modified in accord with the microfossil record and new data.

Based on the occurrence of *Discus shimeki cockerelli*, a species reported only at higher elevations (Chamberlin and Jones 1929; Bequaert and Miller 1973), Paria Lake may represent conditions found roughly 300 m higher today. On the other hand pines, including pinyon and ponderosa, grow at the same elevation and lower in the same drainage today. The thickness of presumably annual depositional units, with a scattering of thicker sands, suggests precipitation amounts similar to (or even somewhat less than) those associated with present climate. Perhaps winter frontal precipitation predominated over summer thundershowers.

The Sentinal Lake clays are seemingly so free of silt at Birch Creek that it is tempting to speculate that heavy local rains associated with present summer circulation were infrequent or absent. It seems possible that a more northerly climate pattern existed here about 4000 years ago.

Coalpits Wash now flows only intermittently, and the streambanks are heavily frosted with efflorescences of gypsum and salt. This is the most arid part of the Park today, thus the presence of lake clays there containing aquatic mollusks attests to a much cooler and wetter climate

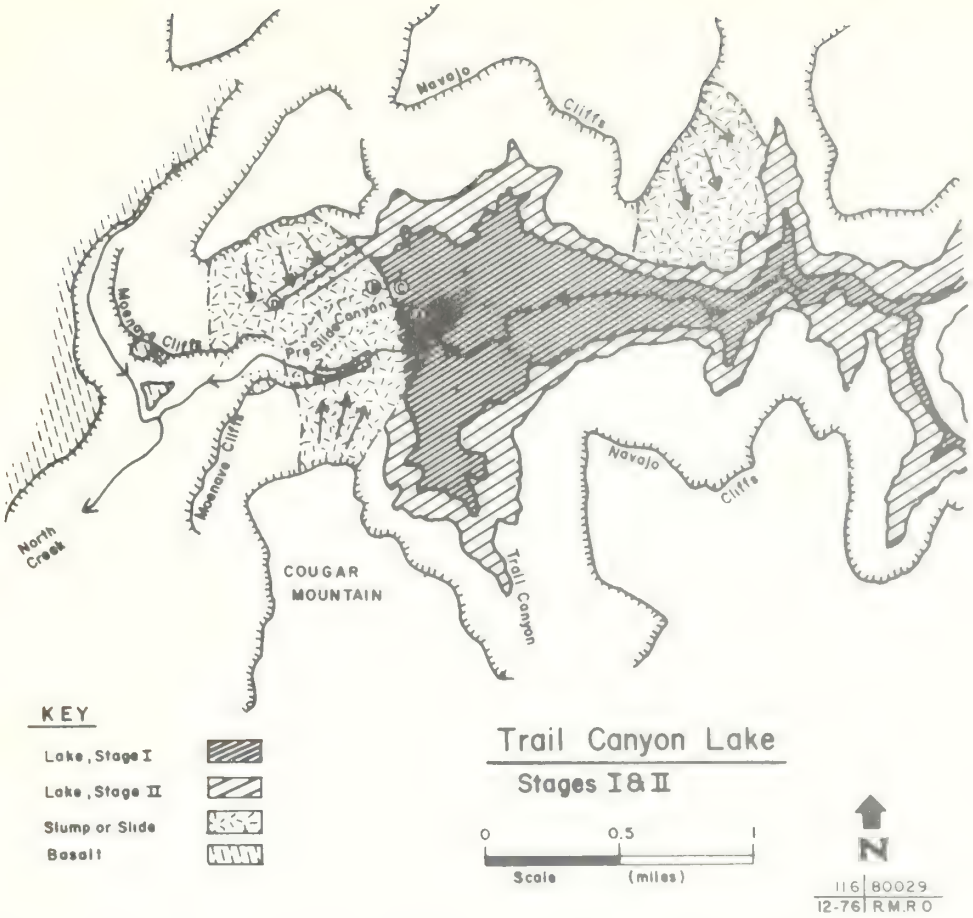

FIGURE 6(a). Map of the Right Fork of North Creek, showing approximate outlines of low and high stages of Trail Canyon Lake, basalt outliers of the North Creek flows, slump and slide deposits, the location of the pre-slide canyon, and sites of measured sections. The lower stage of the lake was presumably caused by lava-damming, followed by a slide from Cougar Mountain. At the end of stage 1 deposition, a slump from the north briefly raised lake level.

than now. The relatively thick sedimentary units, particularly in the track and clay sequences, would indicate large amounts of annual precipitation.

The Right Fork of North Creek now flows year-round from springs at the base of the Navajo sandstone. However, its watershed is not much larger than that of Coalpits Wash, and its headwaters drain almost the same amount of high plateau. Yet the sedimentary units in the Trail Canyon sections are thinner than those in the Coalpits section, It appears that Trail Canyon Lake may have existed in a climate drier than that prevailing during the life of Lake Coalpits. Its climate in relation to the modern one cannot be determined from available data, but the presence of fossiliferous marls and the bison vertebra hint of wetter conditions.

REFERENCES AND NOTES

BEQUAERT, J. C. and W. B. MILLER. 1973. The Mollusks of the Arid Southwest. The University of Arizona Press, Tucson. p. 271.

BEST, M. G. Department of Geology, Bri ham Young Univ., Provo. Potassium-argon dates provided through the courtesy of W. K. Hamblin.

CHAMBERLIN, R. V. and D. T. JONES. 1929. A descriptive catalogue of the mollusca of Utah. Bull. of the Univ. of Utah. 19:4. p. 203.

COLBERT, E. H. Museum of Northern Arizona, Flagstaff. Camel track identification.

EARDLEY, A. J. 1966. Rates of denudation in the high plateau of Southwestern Utah. G.S.A. Bull. 77:777-780.

CRATER, R. K. 1945. Landslide in Zion Canyon, Zion National Park, Utah. Jour. of Geology. 53:116-124.

HEVLY, R. H. 1977. Pollen studies of ancient lake sediments in Zion National Park, Utah. This volume.

JUDSON, S. and D. F. RITTER. 1964. Rates of denudation in the United States. Jour. Geophysical Res. 69:16. pp. 3395-3401.

LANDYE, J. J. Lower Colorado River Basin Research Laboratory, Arizona State Univ., Tempe.

LINDAHL, A. College of Natural Sciences, Utah State Univ., Logan.

NIELSON, R. La R. 1976. The geomorphic evolution of the Crater Hill volcanic field of Zion National Park. M.S. thesis of Dept. of Geology, Brigham Young Univ., Provo.

ROBINSON, W. J. Laboratory of Tree Ring Research, Univ. of Arizona, Tucson.

U.S. GEOLOGICAL SURVEY. 1974. Water Resources Data for Utah, Parts 1 and 2. U.S. Department of the Interior.

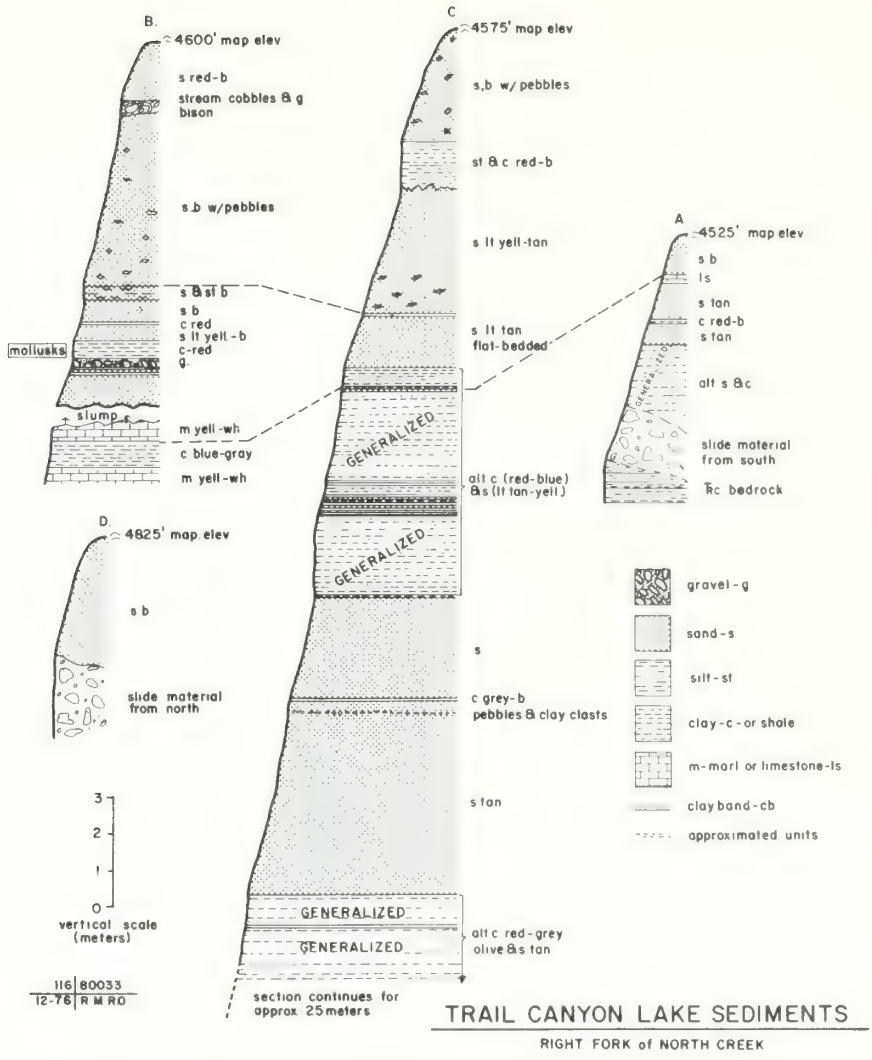

FIGURE 6(b). Cross sections of Trail Canyon Lake sediments. Section at B covers approximately the upper half of the despoits. Clay decreases upward, indicating an increase in shoreline facies toward the end of stage 1. Coarse gravel at top of section C was probably derived from the slump that produced stage II

CHANGES IN THE FLUVIAL DEPOSITS OF THE COLORADO RIVER IN THE GRAND CANYON CAUSED BY GLEN CANYON DAM

Alan D. Howard and Robert Dolan[1]

INTRODUCTION

Most of the sediment formerly carried by the Colorado River through Grand Canyon National Park is now being trapped in Lake Powell, the reservoir of the Glen Canyon Dam. As a result, sandy river terraces, or "beaches" deposited by the turbid pre-dam Colorado are being eroded. These beaches are used as campsites by float trips, and form the most diverse and densely populated natural communities within the canyon; therefore their erosion is of concern to the National Park Service. Although local examples of pronounced erosion can be cited by experienced river guides, a quantitative appraisal of the rate and pattern of change is needed.

Our studies of post-dam changes in the fluvial deposits of the Colorado River include an evaluation of the first ten years of shorefront changes by the use of aerial photography. Because the method has inherent limitations that will be discussed more fully, we have also initiated a field program of surveyed baselines which will be resurveyed at intervals of a few years. The procedures and limitations of these studies will be outlined first, followed by a presentation of results. For a general discussion of the nature of the changes in the fluvial regime caused by Glen Canyon Dam, the reader is referred to papers by Dolan et al. (1974) and by Dolan et al. (this volume).

AERIAL PHOTOGRAPHIC MAPPING

In June, 1973 aerial photography at a scale of 1:7,000 was flown along the 240 miles of the Colorado River from Lee's Ferry to Lake Mead. Photo coverage of portions of the river are also available for the period 1959-66 at scales ranging from 1:10,000 to 1:37,000. When compared to this earlier photography, the 1973 coverage provides an excellent record of about 8 years of changes in shoreline position. Unfortunately, the mapping of these changes is complicated because the river discharge varied between and during the photo flights. Higher river stage is associated with greater river width, but the width-stage relationship depends upon shoreline gradient, which on the sand beaches varies from two degrees to angle-of-repose slopes, about 35 degress. If ignored, the stage differences cause apparent erosion or deposition. For example, if the 1973 discharge was less than the discharge during the pre-dam photo flight, an apparent deposition would be superimposed upon the actual changes. The amount of apparent deposition would depend upon the beach gradient, being larger for lesser gradients.

Therefore, to use measurements made from aerial photographs, variations in discharge must be compensated for. Along about one-third of the 240 miles between Lees Ferry and Lake Mead two or more sets of pre-dam photography were available which spanned the discharge range during the 1973 flight (specifically, miles 0-21, 29-55, 129-150, and 155-177). Shorelines for the pre- and post-dam photography were superimposed at a common scale, as illustrated by Figure 1, showing shorelines mapped between miles 52 and 53 in the Nankoweap Rapids area. A *predicted* pre-dam shoreline for the same discharge as the 1973 photo coverage was drawn by interpolation between the pre-dam shorelines. When compared with the *actual* 1973 shoreline, the predicted pre-dam shoreline indicates total lateral erosion or deposition (Figure 2). Errors and biases that can affect the results include:

1. Errors in registration of shorelines or in drawing of shorelines from the photography. These include cases where overhanging cliffs obscure the shoreline or where the land-water interface is misplaced due to mistaking damp sand for submerged sand or shallow bars for subaerial sand.

2. The discharges assumed for the various sets of photography may be somewhat in error. This is particularly true for the 1973 flight, because discharges released by the dam vary widely during a daily cycle, and the flow must be routed downstream (Figure 3). The exact time of day that the photos were flown is uncertain, and a time of error of two or more hours can lead to 3 or 4 meters of apparent lateral erosion or deposition.

Some of the sandy beaches and tributary fans often slope at an angle of only a few degress. Small errors in estimates of water level on a low-gradient shorefront can lead to large values of apparent erosion and deposition. Fortunately, the pre-dam deposits of cobble bars are also low-gradient, and they are essentially immobile under the low post-dam flows, so where they are present they can provide a partial check against misinterpretation of discharge. For example, a slight amount of deposition is indicated on a cobble bar just below the word "Rapids" in Figure 2. The most likely explanation is a slight underestimation of the discharge at the time of the 1973 flight, for this area is in a section of river that was experiencing a rapid change of stage during the flight (Figure 3). If this error were accounted for, the amount of post-dam deposition on the tributary fan (below the arrow in Figure 2) would be reduced while the estimated extent of erosion in the stippled areas would be increased.

3. The shoreline position under pre-dam conditions was not constant, varying in response to deposition during the turbid summer floods and erosion during the clearer spring meltwater floods. Shoreline positions for higher pre-dam flows sometimes extend farther riverward than those for lower flows (for example, a small area on the right-hand bank near the downstream end of Figure 1). However, the amount of pre-dam variation appears to be small when compared to post-dam changes.

A final problem associated with using aerial photography is that the result is only a two-dimensional record of beach changes. Modifications that occur above normal high water, such as addition or removal of sand and silt by overbank flooding, by wind action, or by human activity occur largely in the vertical dimension and cannot be evaluated by this method.

BENCHMARK SURVEYS

The baseline and profile surveys complement the photo sampling in that the profiles provide

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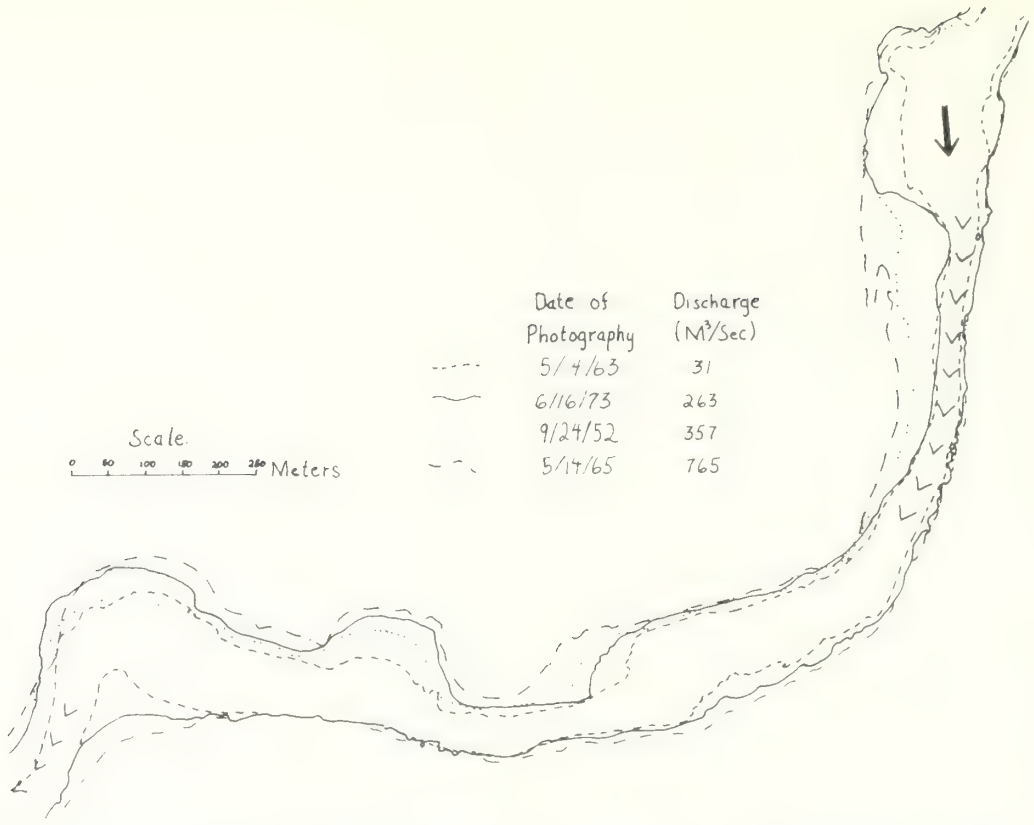

FIGURE 1. Shoreline of the Colorado River between miles 52 and 53 as mapped from various sets of pre- and post-dam aerial photography.

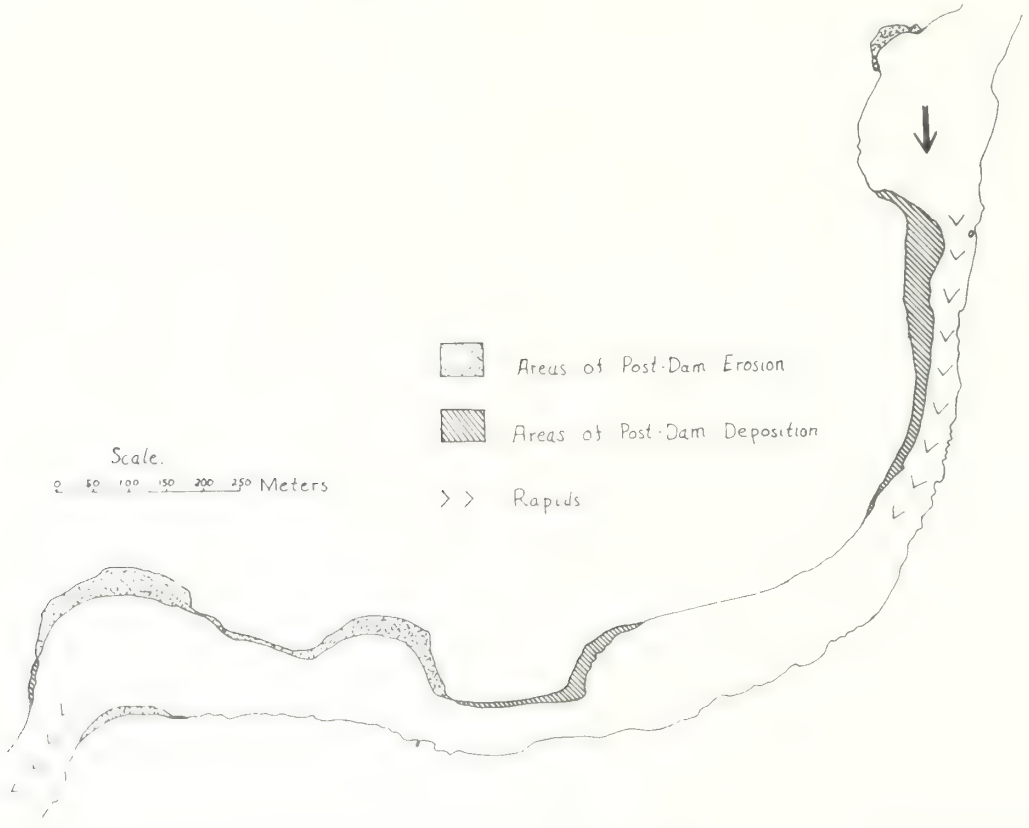

FIGURE 2. Post-dam erosion and deposition between miles 52 and 53, from aerial photographic interpretation.

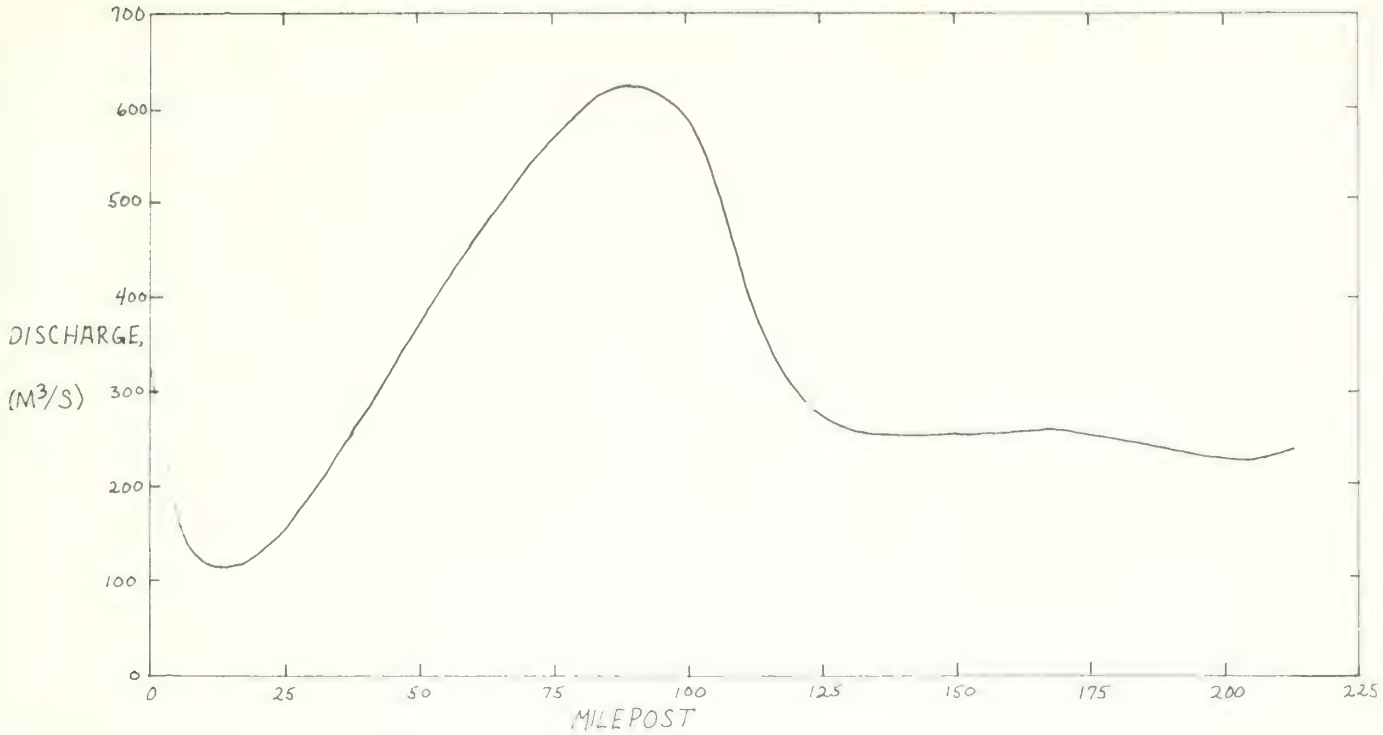

FIGURE 3. Discharge of the Colorado River in the Grand Canyon for noon, July 19, 1973. Pattern of discharges is found by downstream routing of releases from Glen Canyon Dam, taking into account the variation of velocity with discharge.

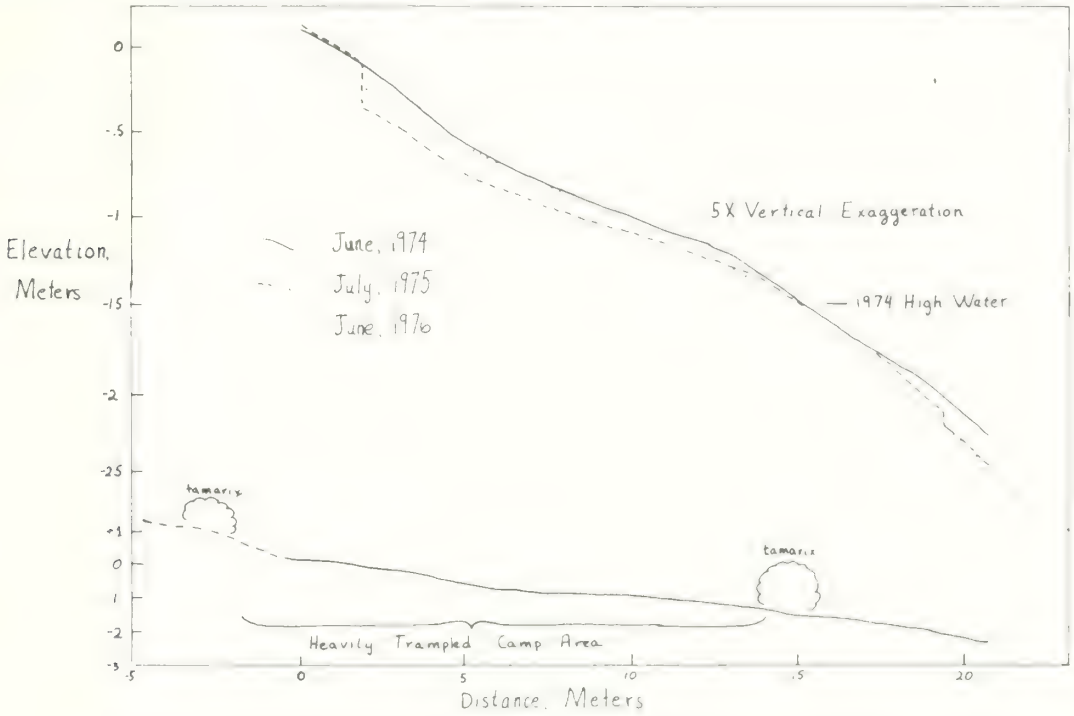

FIGURE 4. Surveyed profiles across beach at Nankoweap campsite, mile 53, showing changes occurring during two resurveys. Lower cross-section to scale, while upper has 5X exaggeration. Arbitrary elevation datum.

a record of changes in elevation through time on both the subaerial beach and the zone periodically submerged. During two float trips made in the summers of 1974 and 1975, 20 baseline sites at campable beaches were established with a total of 38 surveyed profiles. The sites were selected to yield a diverse sampling of beaches as regards morphology, vegetation density, and human impact. The one to three profiles at each campsite run perpendicular to the shorefront, and were chosen to sample the different types of shorefront morphology and vegetation pattern at each campsite. Documentation of the baseline, elevation datum, and profiles is sufficient that a resurvey could be accomplished by persons who did not participate in the original survey. Figure 4 shows a profile at Nankoweap beach, mile 53.0, first surveyed in 1974 and resurveyed in 1975 and 1976. The marked erosion on the portions of the beach above present high water is unusual, having resulted from concentrated runoff during a heavy thunderstorm.

The survey method of assessment of beach changes offers several advantages. The impact of specific events, such as floods, can be determined soon after the event. The surveyed profiles are also more accurate than aerial photographic comparisons, and they are not affected by variations in water level at the time of resurvey. However, there are obvious disadvantages. Information about beach changes is limited to a small number of locations scattered along more than 200 miles of river. The profiles are, like the photographic comparisons, two-dimensional, that is, the vertical and cross-beach dimensions. However, at each survey site the profiles were established at places where the shape of the beach varied little along the shore.

The analysis of systematic erosion and deposition will require observations made over a period of time proportional to the rate of changes. Measurements on the survey sites will have to extend over a period of years to give an accurate picture of the rate and direction of systematic changes.

RESULTS

The sediments found on the terraces can be classified according to age as pre- or post-dam. They may also be divided by agent of deposition into flood deposits, eolian sands, or sands reworked by the river below present normal high water. Similarly, the sediments can also be distinguished by grain size into cohesive silts, which are dominantly silt with a small percentage of clay, silt-sand, with about 30% silt content, and sands, with negligible silt (Figure 5). Several generalities can be made about these deposits:

1. Pre- and post-dam flood terraces are unusually silt-sand.

2. Predam eolian deposits are but little coarser than the flood terraces from which they were derived.

3. Pre-dam cohesive silt was deposited by summer floods and runoff, and it seldom extends more than a few feet above present high water levels. Because of the abundance of water and the fine substrate, they have been covered by a dense vegetative growth.

4. Post-dam beach deposits, reworked by small waves and current, are dominantly sand, with noticeable silt content only along the wide, quiet sections of the river. These deposits are well sorted, and they are the source for most of the post-dam eolian deposits.

Fine-grained deposits below the present high water are being reworked by the river. The rate of response depends upon grain size. Because of the heavy vegetation cover and clay content, the cohesive silts are being cut back more slowly than the sands, forming steep banks with exposed roots (Table 1), which, however, give the *appearance* of rapid erosion.

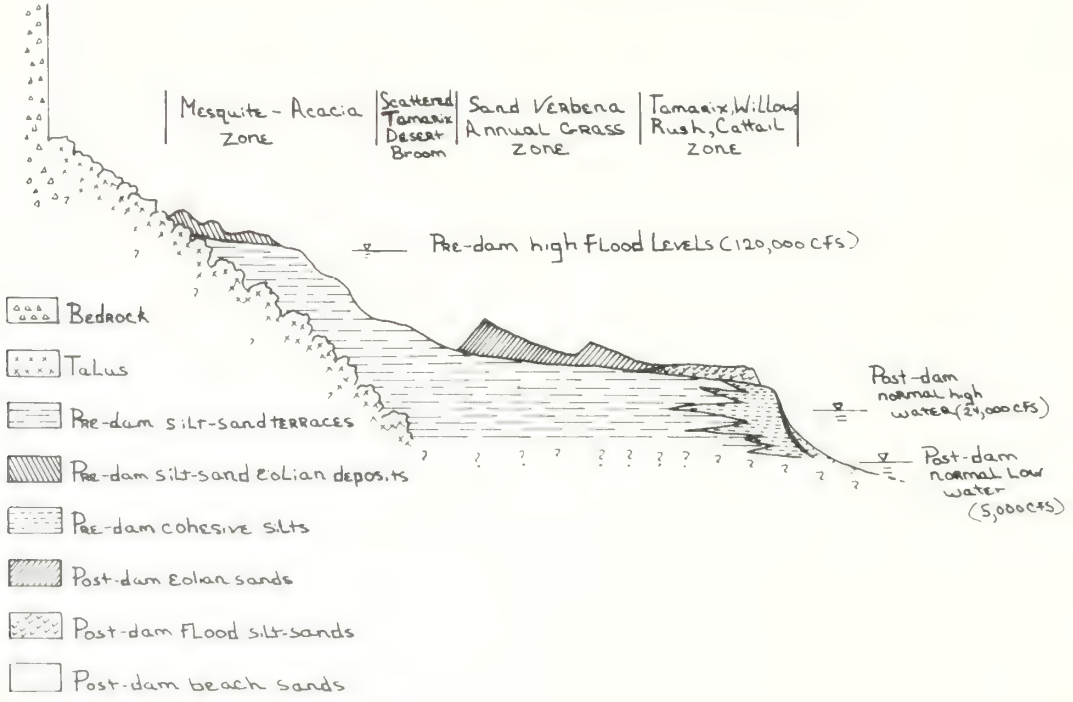

FIGURE 5. Cross-section across typical beach, showing terrace deposits, water level variations, and vegetation zonation.

TABLE 1. Summary of changes to fine-grained fluvial deposits measured by resurvey of base-line profiles.

A. Maximum Changes

Beach Location (mile)	Cross-Section Identification Number	Interval Between Resurveys (years)	Location on Beach [1]	Dominant Grain Size of Beach	Average Gradient	Maximum Lateral Change (meters) [2]	Maximum Vertical Change (meters)
L19.5	1	2	Beach Face	Silt-sand	.091	-4.9	-.85
L19.5	2	2	Beach Face	Silt-sand	.190	-4.0	-.98
L34.7	1	1	Beach Face	Sand	.040	-4.3	+0.73
L34.7	2	1	Beach Face	Sand	.160	0	0
R53.0	1	2	Beach Face	Silt-sand	.152	-1.3	-.24
R53.0	1	2	Camp Area	Sand	.125	-0.9	-.12
R53.0	2	2	Beach Face	Cohesive silt	.200	0	0
R72.2	1	1	Beach Face	Sand	.124	-4.0	-.79
R72.2	2	1	Beach Face	Cohesive silt	.73	0	0
R151.6	1	1	Beach Face	Cohesive silt	.40	+0.7	+.15
R151.6	2	1	Beach Face	Silt-sand	.133	-1.8	-.55
L208.8	1	2	Beach Face	Cohesive silt	.244	-0.8	-.18
L208.8	2	2	Beach Face	Cohesive silt	.400	0	0

B. Average Rates of Change of Beach Face

Dominant Grain Size	Average Gradient	Average Vertical Change (meters/yr)	Average Lateral Change (meters/yr) [3]	Number of Profiles in Sample
Cohesive silt	.39	0	0	5
Silt-sand	.14	-.16	-1.19	4
Sand	.11	-.10	-.67	3

Explanation:

1) Beach Face: Portion of profile below present high water.
Camp Area: Portion of profile no longer inundated. Note: Changes in camp areas are not listed if amount of change recorded is less than expected survey errors.

2) Maximum change observed on resurveyed profile. Zeros are entered if change is less than expected magnitude of survey errors.

3) Calculated by dividing the total areal change of portion of profile below high water by 1) the lateral extent of the profile, and by 2) the number of years between resurveys. Figures quoted are averaged over all profiles.

4) Calculated as above but divided by the vertical extent of the the profile.

5) Zeros indicate average changes less than probable resurvey errors.

Pre-dam flood terraces and post-dam deposits of sand and silt-sand are more easily entrained by present-day flows. The changes measured over one or two years at seven profiles in this coarser-grained sediment (Table 1) are variable, with an average rate of lateral backcutting of about 0.9 meters per year, and a range from 4.9 meters per year of erosion to deposition of 0.7 meters per year. Similarly, the aerial photographic analysis (Table 2) shows rates of erosion exceeding 10 meters per year at a few sites and a few areas that have expanded through deposition. The average rate of erosion of fine-grained shorelines was measured to be 0.3 meters per year. About 16 percent of the mapped sandy terraces were eroding at an average rate exceeding 2 meters per year, while only 6 percent underwent an quivalent rate of deposition (Table 2). Despite possible inaccuracy and bias in these figures, the management implications are clear: severe lateral erosion by the river sufficient to affect camping activities over the next few years will be localized occurrences, and that over the long run, measured in decades, the slow progress of erosion will gradually reduce the number of sandy beaches.

The pre-dam terrace deposits above present-day high water have been modified by three natural processes, eolian transport, rainfall, runoff, and vegetation. Eolian sand movement occurs mostly where vegetation is sparse and the local winds are strong. Under such conditions, rates of vertical erosion or deposition may exceed a meter per year. Rainfall and associated runoff also erode the pre-dam terraces on a localized basis by both sheetflow and gullying. Many terraces are a thin mantle deposited by pre-dam floods on tributary alluvial fans. During a major flash flood the tributary stream can cause wide-scale erosion of the fine-grained mantle.

The one- to two-year resurveys of 13 profiles (Table 1) indicated only one instance where the average amount of vertical erosion above the present high water exceeded the probable survey errors (about 3 cms). This was at the Nankoweap beach shown in Figure 4, due to local gullying during an intense thunderstorm. Since many of these profiles pass through heavily used campsites, the measurements suggest that the combined effects of natural and man-induced erosional processes above high water is slow on the average. However, many paths on steep slopes are inset more than 0.5 meters below adjacent vegetated slopes, indicating erosion rates up to 10 cm per year on steep slopes with high rates of human traffic. Because of the low average rate of vertical erosion, few campsites will become usable due to exposure of the underlying coarse substrate during the next decade.

The absence of large floods since Glen Canyon Dam has resulted in a decreased competency of the post-dam river. Because almost all of the major rapids have resulted from deposition of coarse debris brought by the flooding of tributary canyons, the smaller post-dam river may be forced into a gradient as much as twice its pre-dam value if a major side-canyon flood occurs. However, in order for the river to be so narrowed and steepened, the tributary must flood. The aerial photographic study indicates that 27% of

TABLE 2. Post-dam shoreline changes of the Colorado River, 1965-73, using aerial photography.

Mile[1]	Average Channel Width (meters)	Average Shoreline Change (meters)		No. of Fine-Grained Shoreline with Given Maximum Changes						No. of Fan Deltas with Given Maximum Changes			
		Fan Deltas	Fine Alluvium	--[2]	-[3]	0[4]	+[5]	++[6]	Total Cases	0	+	++	Total Cases
0.5	138.5	0	+5.68	[illegible]	1	1	1	[illegible]	6	0	[illegible]	0	0
[illegible]	101.5	+0.08	-4.61	3	1	5	[illegible]	[illegible]	13	7	[illegible]	[illegible]	[illegible]
3.6	[illegible]	[illegible]	-4.38	[illegible]	3	3	[illegible]	[illegible]	12	3	[illegible]	0	3
[illegible]	98.5	0	+0.63	1	1	[illegible]	[illegible]	1	9	[illegible]	[illegible]	0	[illegible]
[illegible]	88.0	+6.70	+2.64	2	[illegible]	2	[illegible]	[illegible]	[illegible]	3	1	[illegible]	6
7.[illegible]	97.0	+1.06	+1.15	[illegible]	3	1	3	[illegible]	7	2	[illegible]	0	[illegible]
[illegible].7	78.5	+1.51	+0.92	1	1	[illegible]	[illegible]	[illegible]	11	[illegible]	1	[illegible]	[illegible]
10.0	62.5	0	-0.26	1	1	[illegible]	[illegible]	[illegible]	12	1	[illegible]	[illegible]	1
11.3	57.0	+2.62	-0.44	[illegible]	3	[illegible]	1	[illegible]	10	[illegible]	1	1	[illegible]
12.8	41.5	+0.64	-1.29	1	1	[illegible]	[illegible]	[illegible]	8	3	[illegible]	[illegible]	5
[illegible]	46.0	+0.75	[illegible]	[illegible]	0	3	[illegible]	0	3	2	1	0	3
[illegible]	57.5	0	-0.52	1	[illegible]	[illegible]	1	1	9	[illegible]	[illegible]	[illegible]	[illegible]
16.7	66.5	+2.82	+0.57	1	1	[illegible]	1	[illegible]	[illegible]	1	1	[illegible]	5
18.0	59.0	+2.12	+0.94	0	1	7	0	[illegible]	9	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	59.5	+1.86	+3.41	0	3	7	[illegible]	3	[illegible]	[illegible]	3	1	8
20.5	[illegible]	+14.12	+2.20	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7	0	0	1	1
[illegible]	[illegible]	+0.48	+0.33	[illegible]	1	3	1	1	[illegible]	6	1	[illegible]	7
31.2	65.0	[illegible]	-3.57	1	[illegible]	[illegible]	3	[illegible]	[illegible]	[illegible]	0	[illegible]	9
33.0	65.0	+0.29	-1.54	[illegible]	3	[illegible]	1	[illegible]	[illegible]	[illegible]	1	[illegible]	5
[illegible]	80.5	+1.20	-6.09	3	[illegible]	[illegible]	1	[illegible]	10	[illegible]	[illegible]	1	[illegible]
[illegible].5	70.5	+0.38	-5.01	[illegible]	3	[illegible]	0	0	13	[illegible]	[illegible]	0	[illegible]
36.9	78.5	+[illegible].77	-2.88	3	[illegible]	6	[illegible]	[illegible]	11	[illegible]	[illegible]	1	3
38.1	83.5	+2.78	-2.15	[illegible]	[illegible]	[illegible]	[illegible]	1	[illegible]	1	2	[illegible]	[illegible]
39.7	85.0	+1.49	-5.51	[illegible]	1	[illegible]	0	1	[illegible]	[illegible]	1	[illegible]	[illegible]
40.9	88.5	+1.49	-1.26	3	[illegible]	3	[illegible]	[illegible]	[illegible]	1	1	0	[illegible]
[illegible]	94.5	0	-2.50	[illegible]	3	1	1	[illegible]	5	1	[illegible]	[illegible]	1
43.8	81.0	+5.52	-4.00	[illegible]	[illegible]	[illegible]	[illegible]	2	16	3	1	1	5
45.3	95.5	+2.83	-6.16	[illegible]	0	7	1	[illegible]	[illegible]	1	[illegible]	1	2
46.7	104.5	+0.92	-9.05	[illegible]	0	[illegible]	1	1	13	5	0	1	6
48.1	102.0	+1.23	-5.00	[illegible]	1	9	[illegible]	[illegible]	15	[illegible]	0	1	[illegible]
49.5	110.0	[illegible]	-7.08	3	1	[illegible]	[illegible]	0	[illegible]	[illegible]	[illegible]	0	5
50.7	93.5	0	-8.42	[illegible]	[illegible]	5	1	0	10	3	[illegible]	0	[illegible]
52.5	113.5	+2.82	-1.41	[illegible]	2	3	[illegible]	1	10	[illegible]	1	1	[illegible]
129.5	50.0	+6.84	+2.38	[illegible]	[illegible]	5	[illegible]	1	[illegible]	[illegible]	1	[illegible]	[illegible]
130.8	58.0	0	-2.10	[illegible]	[illegible]	[illegible]	3	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
132.2	49.0	+0.16	-9.17	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
133.5	60.5	+0.43	-4.95	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
135.0	48.0	+1.44	-4.60	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
136.4	48.0	[illegible]	-4.37	[illegible]	[illegible]	10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5
137.7	63.0	+0.07	-1.48	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
139.4	56.5	+1.27	-4.39	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
140.5	51.0	[illegible]	-4.01	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	55.5	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
143.4	[illegible]	+14.87	-3.61	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
155.8	42.8	+2.13	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
157.3	45.0	+1.78	-3.08	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
158.8	[illegible]	+1.77	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
160.4	48.5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
161.5	50.5	+2.15	+0.19	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
163.2	54.5	+1.43	-0.84	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	63.5	+2.57	+0.21	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
166.5	[illegible]	[illegible]	+0.42	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	76.5	+2.41	-2.89	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
169.4	68.0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
170.8	65.0	[illegible]	+2.72	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
172.3	72.5	+0.42	-4.54	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
173.5	68.0	+3.08	+2.23	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
175.1	69.5	+1.33	-2.97	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
176.4	81.5	0	-3.52	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Averages:	[illegible]	+0.22	-0.31										
				Totals:	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
				Percent of Totals:	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Explanation:

1) Center of 1.5 mile segment of river.
2) Maximum lateral erosion of fine-grained shoreline segment greater than 15 meters in 8 years.
3) Maximum lateral change between 0 and 15 meters of erosion.
4) [illegible].
5) Maximum lateral change between 0 and 15 meters of deposition.
6) Greater than 15 meters of deposition.

tributary fans in the study sites have built outward, but narrowing of the river by more than 15 meters has occurred on only 10% of the fans (Table 2). Catastrophic narrowing and steepening of rapids is very uncommon, the most notable example being the creation of a major rapid at Crystal Creek (mile 98.2) in the mid 1960's.

Constriction of the river by tributary floods may make the rapids impassable to float trips and can raise the level of the water by several feet a mile or more upstream. Such major floods are rare and unpredictable in specific occurrence, and even their frequency is uncertain. Human adjustment to any such major flood will have to be done on an after-the-fact basis, but the likelihood of a flood of sufficient magnitude to create an impassable river over the next few decades seems remote.

LITERATURE CITED

DOLAN, R., B. HAYDEN, A. HOWARD, and R. JOHNSON. 1977. Man's impact on Colorado River fluvial deposits within the Grand Canyon. Proc. 1st Conf. Sci. Res. in the National Parks, this volume.

DOLAN, R., A. HOWARD, and A. GALLENSON. 1974. Man's impact on the Colorado River in the Grand Canyon. Am. Scientist. 62:392-401.

MONTANE COCHISE CULTURE SITES IN CORONADO NATIONAL MEMORIAL

Yvonne G. Stewart[1]

In response to a proposed land exchange between the National Park Service and the U.S. Forest Service, four staff archeologists of the Western Archeological Center, Tucson, conducted an archeological survey of 5,000 acres within Coronado National Memorial and the adjacent Coronado National Forest during March and April 1975. The survey was accomplished in accordance with the strategies and techniques designated to test hypotheses developed within a previously conceived research design (Stewart and Purves 1975). Because of the extreme steepness of much of the terrain, only those lands with a slope of 30% or less were 100% surveyed. In addition, all flat ridges, all terraces, and all drainages were examined until the crew reached a point where ropes would be necessary. In this way 50% of the total land area and at least 75% of the culturally utilizable land area was examined. In addition to several historic ranching and mining sites, eight prehistoric Cochise Culture sites, primarily of the Chiricahua Stage, were located.

THE SURVEY AREA AND ITS ENVIRONMENT

The survey area included a slice of land which parallels and is adjacent to the Mexican border and which transects both a southern extension of the Huachuca Mountains and a mile of pediment on both the east and west sides (see Fig. 1). The extremely precipitous Huachuca Mountains extend for 25 miles through southeastern Arizona and northern Mexico along a northwest-southeast axis. Immediately to the east lies the very long and broad San Pedro Valley. Alluvial fans or pediments gradually slope out from the mountains to the Santa Cruz River to the west and the San Pedro River to the east. Emerging from the western slopes of the mountains and continuing through the pediment are a series of washes, which are cut to depths of up to 50 feet with very steep sides. Access through the mountains is provided by Montezuma Pass near the center of the survey area. To the east, Montezuma Canyon, broadened and deepened by the now intermittent Montezuma Creek, extends into the pediment. Except at its headwaters, terraces border the creek bed, occasionally changing from side to side. Other deep washes north of Montezuma Creek intermittently flow east into the San Pedro River. There are only a few areas within the district flat enough for human habitation. These include the alluvial fans or pediments to the east and west of the mountains, the terraces of Montezuma Creek, and a few isolated ridges within the mountains.

Geologic formations in and around the memorial consist of complexly interrelated volcanics, intrusives, and sedimentary rocks (Hayes and Raup 1968). These natural rock formations provided prehistoric inhabitants with numerous suitable raw materials for stone tool manufacture. These stones included various cryptocrystallines, granite, quartzite, adesite and basalt. With the exception of obsidian, all lithic materials used by the Cochise Culture inhabitants were immediately available in the form of gravels, boulders and outcrops, usually directly on site.

Opinions vary concerning climatic conditions in southeast Arizona during the time period under consideration--circa 7000 B.C. to 300 B.C. (Antevs 1955; Martin 1963; Mehringer 1967). There were several periods of greater effective moisture than at present as well as extremes in advances and regressions of vegetation zones along with variability in amounts of available surface water. Precipitation in the Huachucas varies with altitude. At present it ranges from 12 to 30 inches annually and comes in two seasons. These seasons of rainfall produce corresponding seasons of growth in native plants. Temperatures fluctuate from highs in the low 100's during the summer to below freezing during the winter (Denver Service Center 1975).

Yaqui Spring, on the western side of the mountains, is now the only year-round source of water. On the east side of the mountains, Montezuma Creek, now an intermittent stream, flowed perennially until the early 1940's. Virtually all prehistoric sites and isolated artifacts are located adjacent to watercourses or springs.

The Huachucas are famous for the great abundance and variety of both plant and animal life in comparison to the surrounding environments. This is directly related to isolation of species from broad adjacent areas following the Pleistocene, modern topographic extremes, and climatic variations (Wallmo 1955). Four vegetation zones occur within the surveyed area. Desert Grassland is found at elevations between 4,000 and 5,000 feet. It contains over 50 gramonoid species as well as many forbs. There is frequent invasion by oaks, agaves, yuccas, and cacti. It is one of two major grassland areas in Arizona untouched by invasion of mesquite and other shrubs. Oak woodland is found at elevations ranging from 4,000 to 6,500 feet. Major upper story vegetation within this community includes Emory oak, Arizona oak, and Mexican blue oak. There is an understory of shrubs such as manzanita and buckthorn as well as succulents, cacti, herbs and grasses, including sotol and beargrass. Oak/pinyon/juniper woodlands usually occur at slightly higher altitudes depending on slope and other factors. Major species include Utah juniper, alligator juniper, Mexican pinyon, and mountain mahogany. Here shrubs completely replace the grassy understory. The riparian community exists along stream channels which follow canyon bottoms. Vegetation is dense, larger, and relatively unchanging regardless of the vegetation zone through which it passes. Plants from higher altitudes extend to lower elevations. Major species include Arizona walnut, Arizona sycamore, cottonwood, velvet ash, Rhus, willow and wild grapes (Lowe 1964; Wallmo 1955; Denver Service Center 1975). These four vegetation zones offer an unusually rich variety of raw resources for use by man.

The mountains are known to contain 78 species of mammals, a diversity of insect life, 14 kinds of hummingbirds, and about one quarter of the bird species that breed in North America. Several species, such as the Mexican wolf and prairie falcon, are listed as rare or threatened. Many animals, such as the coatimundi, reach their limits of distributional range (Wallmo 1955; Hoffmeister and Goodpaster 1954; Denver Service Center 1975). Obviously, if the prehistoric environment was at

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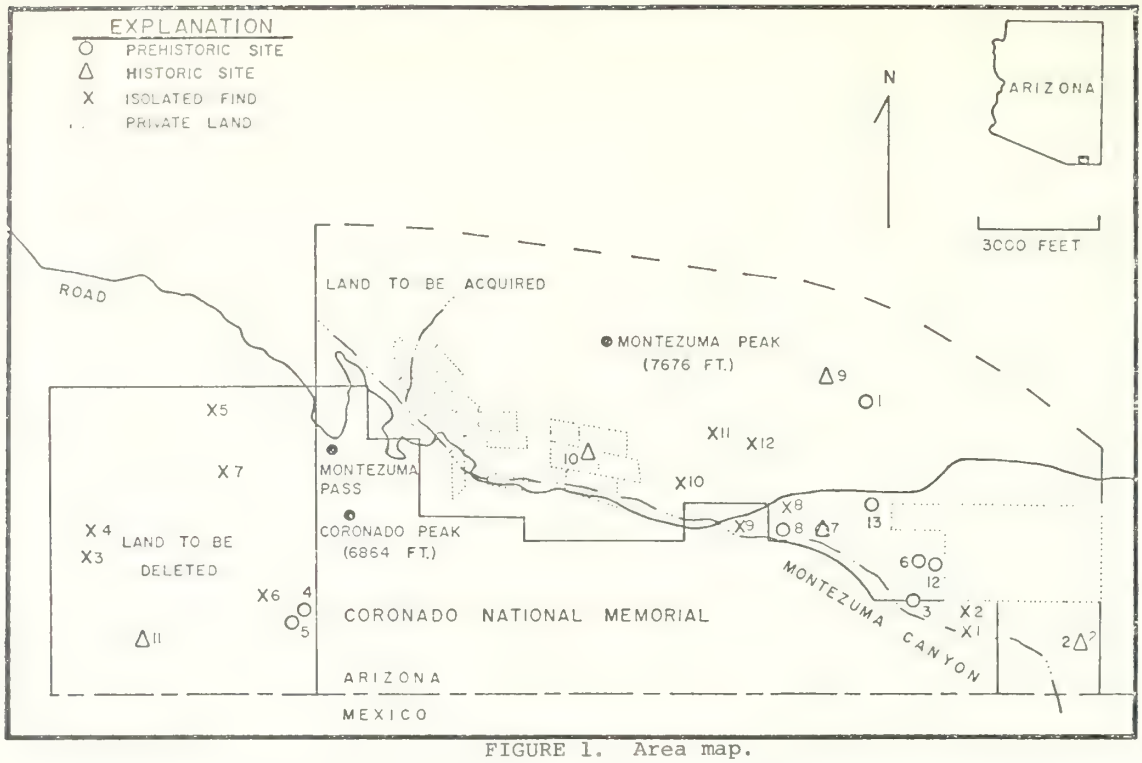

FIGURE 1. Area map.

all like the present, there was abundance and variety in plant and animal life, as well as inorganic raw materials, far beyond survival requirements for a hunting and gathering way of life.

THE SITES

The eight sites each consist of very light scatters of chipped and ground lithics along with associated surface features (see Table 1). Six of the sites may contain subsurficial deposits. Sites are located on both the east and west pediments adjacent to the steep rise of the mountains. An overview of the surrounding terrain, usually of nearly fifty miles, is offered from all of them. The one exception to this topographic rule is a butchering site (CORO 8) which is located well within Montezuma Canyon on a terrace overlooking the creek bed. All are found adjacent to watercourses or springs at elevations of 5,000 to 5,500 feet. Six cluster near the mouth of Montezuma Canyon or near Yaqui Spring, both year-round sources of water until recently. Two exceptions to this clustering are the butchering site and another single activity site (CORO 1), located one mile north of Montezuma Creek along an unnamed drainage. In addition, most sites are located in ecotones allowing for immediate use of several vegetation communities.

Areal extent of the scatters varies from a very small 5 meters diameter to the dimensions of 265 x 175 meters. Lithic density was extremely light with the highest recorded per square meter being .12 as determined by dividing the number of recorded lithics by the number of square meters per site. Compared to a range of .53 to 40.79 per square meter for Cochise Culture sites located by Whalen (1971, 1975) 30 miles north in a similar topographic situation, these are light scatters indeed.

Only two types of surface features were discovered. The first includes oval to circular arrangements of both fractured and unfractured rocks, sometimes containing mano or metate fragments. These are probably hearths or roasting pits. The second type of feature is a slight circular depression, four meters in diameter, in which grow a dense stand of Chenopodium and amaranth. It is possible this feature is a structure floor.

Temporally diagnostic projectile points indicate that four sites date from the Chiricahua stage while one site was used during both the Chiricahua and San Pedro stages. The remaining three sites are assumed to belong to the Cochise Culture on the basis of their lack of pottery and the types of ground stone artifacts displayed, as well as the similarity of site configurations, lithic materials used, and topographic location in relation to those sites which had diagnostic points. Because there is a dearth of good radiocarbon dates in association with pre-ceramic sites in southeast Arizona, there can be no exact temporal placement. There is much disagreement among archeologists concerning these dates. On the basis of geological and palynological determinations, the widest extremes have ranged from 6500 B.C. to 300 B.C. (Whalen 1971).

Except for the projectile points, artifacts were consistently similar to those originally defined for the Chiricahua and San Pedro stages by Sayles and Antevs (1941). Like the projectile points, other artifacts indicative of the San Pedro stage existed at only one site. Ground stone implements consisted of several types of one hand manos, including those distinctively pitted on either side, pestles, and both slab and basin metates. Chipped stone artifacts included a variety of cutting tools, very large plano-convex adzes, smaller plano-convex scrapers, a variety of chopping tools both unifacially and bifacially retouched, and a variety of side and end scrapers. The use of both retouched and unretouched flakes for cutting and scraping activities was common. Both hammerstones and large flat granitic stones which appeared to have been used as anvils existed at several sites.

In addition to these, two very uncommon artifacts were discovered. Prior to the survey, a park naturalist discovered a wooden artifact in the shape of a very large flat meat cleaver with a wide handle wedged into a small rock shelter

TABLE 1.

Site No. Name	Site Type	Possible Sub-Surficial Material	Phase	Altitude	Vegetation Zone
CORO 1 ARIZ EE:12:25	Work Camp	Yes	Unknown	5325	Oak woodland
CORO 3 ARIZ EE:12:27 Garbage Dump Site	Base Camp	?	Chiricahua San Pedro	5000	Riparian-Oak woodland-Grassland ecotone
CORO 4 ARIZ EE:11:12 Yaqui Springs Site	Base Camp	Yes	Chiricahua	5500	Oak woodland-pinyon juniper-riparian ecotone
CORO 5 ARIZ EE:11:09 Yaqui Springs Site	Base Camp	Yes	Probably Chiricahua	5480	Oak woodland-pinyon-juniper-riparian ecot.
CORO 6 ARIZ EE:12:28	Work Camp - Vegetal Materials	Yes	Unknown	5025	Oak woodland-Grassland ecotone
CORO 7 ARIZ EE:12:29	Base Camp or Several Work Camps	Yes	Unknown Prehis/His.	5075	Oak woodland-Grassland ecotone
CORO 8 ARIZ EE:12:30	Work Camp - Hunting	No	Chiricahua	5175	Oak woodland-riparian ecotone
CORO 12 ARIZ EE:12:32	Work Camp	?	Unknown	5000	Oak woodland-Grassland eco.

Site No. Name	Possible Structure Floor	Hearth	Associated Rock Shelter	Projectile Point	Mano/Fragment	Slab or Utah Metate/ Fragments	Double Mortar	Slab Pigment Mixer	Pestle	Plano-Convex Scraper	Other Scraper	Cutting Tool	Biface	Chopper	Core	Hammerstone Flakes	Wooden Paddle	Hammerstone	Site Size
CORO 1 ARIZ EE:12:25				x (1)		x					x			x		x		x	6.0m x 18.0m
CORO 3 ARIZ EE:12:27 Garbage Dump Site		x ?		x (3)		x		x			x	x	x	x	x	x			90m x 60m
CORO 4 ARIZ EE:11:12 Yaqui Springs Site			x	x (2)	x						x	x				x	x		50m x 25m
CORO 5 ARIZ EE:11:09 Yaqui Springs Site	x	x (2)	x	x (1)	x ?						x				x	x		x	100m x 70m
CORO 6 ARIZ EE:12:28					x	x	x			x		x	x	x	x	x		x	25m diameter
CORO 7 ARIZ EE:12:29		x (2)		x (1	x	x			x	x	x	x	x	x					265m x 175m
CORO 8 ARIZ EE:12:30				x (5)						x		x	x						55m x 65m
CORO 12 ARIZ EE:12:32		x				x									x				5m diameter

above the Yaqui Spring site (Kuncl 1968). One edge, which would be the cutting edge on a cleaver, the bottom edge of this "blade," and the rounded corner where the "blade" and handle meet had all been fire hardened and sharpened. These sharpened edges all displayed both wear and a sheen, especially at the corner. The tool was shaped from a single piece of wood. It is thought that this tool was used as a scythe for harvesting grasses. While this wooden tool was collected from near CORO 4 and CORO 5, there is no direct contextual evidence to indicate it is Archaic. The second unusual artifact was a sandstone slab with irregular sides measuring about 25 x 15 centimeters with a thickness of 4 centimeters. One flat side was lightly pecked for a grinding surface and in places was worn nearly smooth. This side was heavily stained with a red pigment, probably hematite. The other side contained two straight sided cups 2 centimeters deep and 4 centimeters across. There are fewer pigment stains on this side. The slab was apparently used for crushing, mixing, and grinding pigment.

Following Whalen's (1971, 1974) designations, which were based upon an earlier survey and surface collection of sites within 100 square miles nearby, two major site types, base camps and work camps, are represented. Base camps are defined as those used primarily for maintenance activities such as food preparation and storage, mid- and final-stage lithic manufacture, basket-weaving, woodworking, and other tool preparation. Sites are usually larger and display a variety of artifacts, features, and activity areas. Work camps are those used for procurement activities such as hunting, butchering, lithic quarrying, or gathering of specific plants. They are satellites of base camps and are usually smaller with fewer activities represented.

Four sites at Coronado were designated base camps and four as work camps. It must be stressed that these sites, unlike Whalen's, were not collected with artifacts later being analyzed in the laboratory. The designations are made on the basis of field determinations only. However, because the areal density of sites was so light and because the on-site lithic density was so light, we were able to accurately map and observe each individual artifact. On this basis, we believe the site type designations are correct. Only one site (CORO 7), the largest in the survey, presented real difficulties because of heavy alluviation. Here lithic concentrations were visible in six different areas either disturbed by cattle or eroded by recent shallow channeling. Each area displayed a completely separate set of artifacts in terms of type designation as well as lithic materials used. Hearths or roasting pits were present at two of the concentrations. The site was arbitrarily designated a base camp but may, in fact, be six individual work camps. This could only be determined by excavation and analysis.

Other sites were easier to determine. Perhaps the clearest example is that of the previously mentioned butchering site (CORO 8). The site is located on a terrace affording an overlook of Montezuma Creek. Artifacts included bifaces, one knife, two chopping tools, side scrapers, five projectile points, thin, sharp utilized flakes and cores or chunks. All of the projectile points exhibited impact fractures. The other artifacts are all those used by hunting and gathering groups today for various aspects of butchering including cutting, fleshing, and bone fracturing. One projectile point, a biface, and several of the scrapers and flakes were made on the spot from an outcrop of unusually workable quartz located about 15 meters away. The site is clearly a butchering work camp where opportunistic quarrying of stone took place.

While many areas of other sites, particularly the base camps, displayed either units apparently homogenous or at least undifferentiated as to activity, all sites had several areas which clearly showed separate activities. This even included an isolated grouping of scraper, discoidals, planes, and choppers, the relationship of which Whalen (1971) had previously detected by computer. Following Wilmsen's (1970) edge angle studies this grouping was probably used for woodworking. Following both Wilmsen and Whalen, at least 25 separate activities are suggested by the artifact types and configurations.

Both the settlement pattern and the artifacts used indicate hunting and gathering groups following a migratory pattern. Trade or a much wider territorial range is suggested by obsidian thumbnail-shaped scrapers found at several sites. No thorough studies of Cochise Culture social organization have been attempted, but it is generally thought that bands composed of several extended families made up these groups. Because of the light scatter and the constricting topographic situation at several sites, it seems likely that no more than a microband was making use of the sites.

The sparseness of sites and of artifacts within the sites raise several other questions. If these two criteria are used as indicators of intensity of utilization, one would have to suppose that this region, which at present seems to offer so much for hunting and gathering groups, was hardly used at all. Why not? Several alternative hypotheses are offered. First, subsurficial material may exist at six of the sites, and it is possible that the density increases subsurficially. Second, both the climate and the vegetation may have differed from the present to make this region undesirable to people then. This seems particularly plausible when one considers the fact that pediment sites in Whalen's area are a thousand feet lower than they are in the Coronado region. Third, even without much of an environmental change people may have been opting for a particular range of plants and animals which did not usually include those found in the Coronado region. Certainly the types and abundance of species between the two regions are different now. A corollary to this is that the Coronado region would have been used only in times of stress. Fourth, several canyons further north in the Huachucas and spaced at about 10-mile intervals are broader, deeper, and offer access much further into the mountains. They have not been surveyed for Cochise sites. It is possible that these canyons, rather than Montezuma Canyon, were chosen for offering optimum access to the same, or more, types of foods and other resources. The answers, of course, can only be discovered with further survey, excavation and analysis.

LITERATURE CITED

ANTEVS, ERNST. 1955. Geologic-climatic dating in the West. American Antiquity, Vol. 20, No. 4, pp. 317-335. Salt Lake City.

DENVER SERVICE CENTER. 1975. Draft environmental assessment, proposed master plan, Coronado National Memorial, Arizona. Ms., on file at the Western Archeological Center, Tucson.

HAYES, P. T. and R. B. RAUP. 1968. Geologic map of the Huachuca and Mustang mountains, southeastern Arizona. USGS Miscellaneous Geologic Investigations Map, 1-509.

HOFFMEISTER, D. F. and W. W. GOODPASTER. 1954. The mammals of the Huachuca mountains, southeastern Arizona. Illinois Biological Monographs 24(1): 1-145.

KUNCL, ERNEST W. 1968. Coronado National Memorial archeological research management plan. Ms., on file at the Western Archeological Center, Tucson.

LOWE, CHARLES H. 1964. Arizona landscapes and habitat: in the vertebrates of Arizona, edited by Charles H. Lowe, pp. 1-132. The University of Arizona Press, Tucson.

MARTIN, PAUL SCHULTZ. 1963. The last 10,000 years, a fossil pollen record of the American southwest. University of Arizona Press, Tucson.

MEHRINGER, P. J., JR. 1967. Pollen analysis and the alluvial chronology. Kiva 32(3):96-101.

SAYLES, E. B. and ERNST ANTEVS. 1941. The Cochise culture. Medallion Papers 29.

STEWART, YVONNE G. and SUSAN PURVES. 1975. Coronado National Memorial survey report. Western Archeological Center, National Park Service, Tucson.

WALLMO. O. C. 1955. Vegetation of the Huachuca mountains, Arizona. The American Midland Naturalist, 54(2):466-479.

WHALEN, NORMAN. 1971. Cochise culture sites in the central San Pedro drainage, Arizona. Unpublished Ph.D. dissertation. Department of Anthropology, University of Arizona.

_____. 1975. Cochise site distribution in the San Pedro Valley. The Kiva, 40(3):203-211.

WILMSEN, EDWIN N. 1970. Lithic analysis and cultural inference: a Paleo-Indian case. Anthropological Papers of the University of Arizona, No. 16. The University of Arizona Press, Tucson.

NAVAJO ARCHEOLOGY IN CANYON DEL MUERTO: THE HISTORIC STUDY OF THE MODERN INHABITANTS OF CANYON DE CHELLY NATIONAL MONUMENT, ARIZONA

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This paper deals with a locational analysis of Navajo settlement in the Canyon del Muerto section of Canyon de Chelly National Monument. The data are derived from historical and archeological sources, principally the Canyon del Muerto Survey conducted by the Western Archeological Center during the summer and fall of 1975.

Canyon de Chelly National Monument is located in northeastern Arizona in the central portion of the Navajo Reservation (Figure 1). The monument was established in 1931 with the provision that there would be no interference with Navajo rights and title to the land. Today the canyon system is seasonally occupied by about 200 people, with others living on the adjacent plateau within the monument boundary, which extends one-half mile from the canyon rim.

The canyon system is cut down as much as 350 meters into the predominantly sandstone deposits of the Defiance Plateau. The canyon system is composed of three major canyons, the northernmost being Canyon del Muerto (Figure 2). The monument environment varies from east to west. The plateau is at its highest elevation on the east near the Chuska Mountains. There the vegetation consists of dense pinyon-juniper forest mixed with occasional Ponderosa pines and many sagebrush clearings, especially in association with seasonal washes. The pinyon-juniper forest thins to sparse tree cover gradually toward the west as the elevation decreases. The lower plateau is largely grassland.

The mouth of the canyon has a wide streambed flanked by cottonwood trees. The sandstone walls of the canyon increase in height toward the east. The lower portion of the canyon is dry much of the year, but the stream flows during the spring and after heavy rains in the late summer. However, since the water table is high, water may be obtained easily at any time merely by digging a shallow well in the streambed. Arable land is found on alluvial benches flanking the stream, particularly in the central portion of the canyon. In the upper half of the canyon, the stream is narrower and confined to an arroyo up to three meters deep. In the upper portion of the canyon, the sandstone walls are sheer, and steep rocky talus slopes take up much of the canyon bottom, leaving little arable bench area.

The Canyon del Muerto Survey relied primarily on a series of systematic transects running basically north-south and thus cross-cutting the canyon and plateau environmental zones. The survery, augmented by previous salvage excavation and preliminary survey work in the area (James and Lindsay 1973), provided a 16% sample of the del Muerto section of the monument. The Navajo data were recovered with the purpose of examining the changing relations between the Navajo and their natural and social environments as reflected in changing settlement patterns. The locational analysis utilized a number of techniques, including bivariate correlation analysis, t-tests, binomial tests, chi-squares, and non-statistical methods. The data consisted of 99 Navajo habitation sites, containing dwellings (i.e., hogans) and which could be dated to one of the two broad temporal periods. Pre-Fort Sumner period sites are those occupied prior to the forced relocation of the Navajos to Fort Sumner, New Mexico, following their military defeat by the U.S. Cavalry in the campaign between 1863 and 1868. The Post-Fort Sumner period includes all sites occupied after the return from Fort Sumner, between about 1868 and the present (Figure 3). The locational analysis was conducted in order to test a model of Navajo settlement stragegy which focused on the interaction of three basic factors: subsistence, defense, and transportation.

The archeological evidence for subsistence during the 18th and 19th centuries suggests a mixed economy involving sheep herding, agriculture, and hunting-gathering; similar to characterizations of Navajo subsistence found in ethnographic accounts. Historical documents recording comments of Spanish and American observers support the notion of a mixed economy in their consistent reports of sheep herds and flourishing corn fields and peach orchards in de Chelly (Brugge 1965;6; Littell 1967:599-601, 663; and Walker and Shepherd 1964:39,47). The ready availability of arable land and the unusual reliability of the water source make de Chelly unique on the Navajo Reservation for its agricultural potential. During the 20th century, cattle herding has become a more important part of Navajo economy in the area.

Such a mixed economy would have produced seasonal variation in requirements. There would be a perpetual need for pasture and water. Summer farming would require access to arable land and winter weather conditions would necessitate wood for fuel and substantial housing. The differential distribution of arable land, pasture, water, and wood produces spatial differentiation in land utilization. Assuming that settlements tend to allow access to critical resources, seasonal variation in settlement should be evident.

The second critical factor, that of defense, would change according to cycles of war and peace with Utes, Zunis, Spanish, and Americans. Defense tactics consisted of flight to places of refuge. The historical record establishes that the second half of the 18th century was a time of relative peace with the Spanish but of warfare with the Utes. It is during this period that the first recorded Navajo migration into de Chelly occurred (Hester 1962:78; Matson and Schroeder 1957:356; Reeve 1960:202; and Thomas 1932:350). The archeological record supports this--our earliest reliable dendrochronology dates being 1753 and 1773. The first documented Spanish penetration into del Muerto occurred in 1805 and resulted in the famous and aptly named incident at Massacre Cave. This inaugurated an increasingly intense conflict between Navajos and the Spanish, and later the Americans, which culminated in the Kit Carson campaign of 1863 and the subsequent incarceration of the Navajos at Fort

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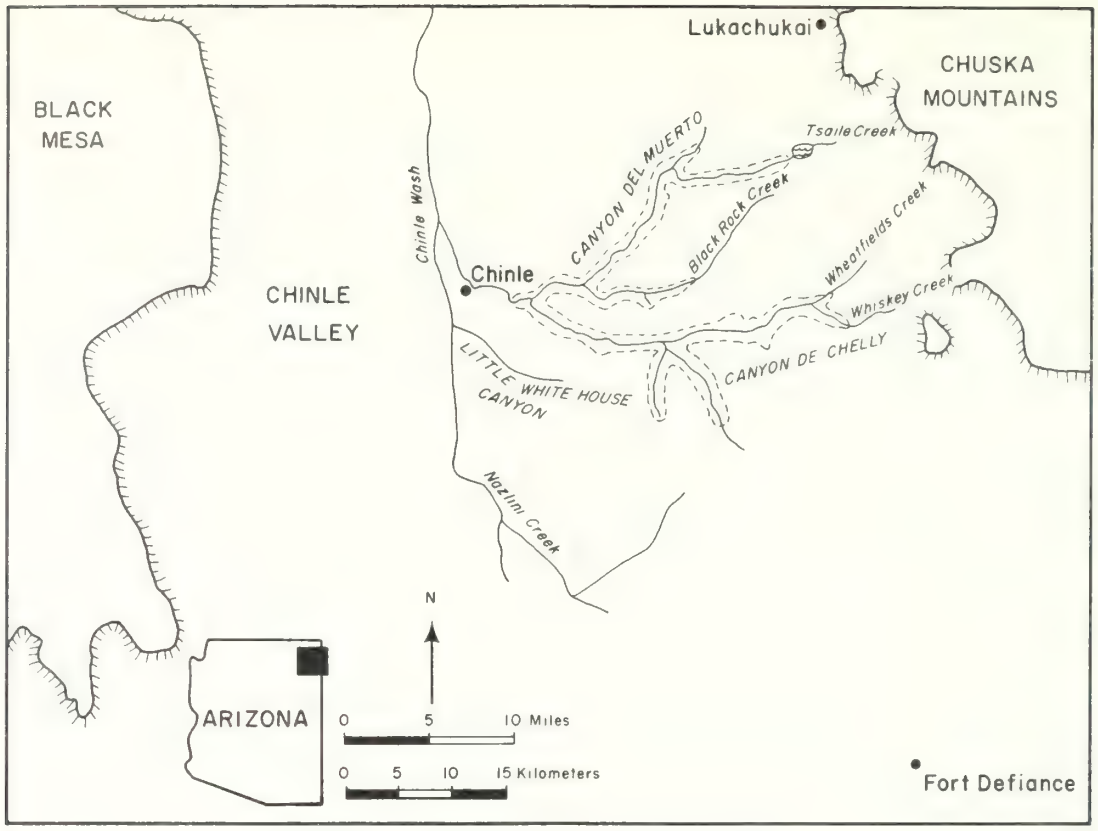

FIGURE 1. The Canyon de Chelly region.

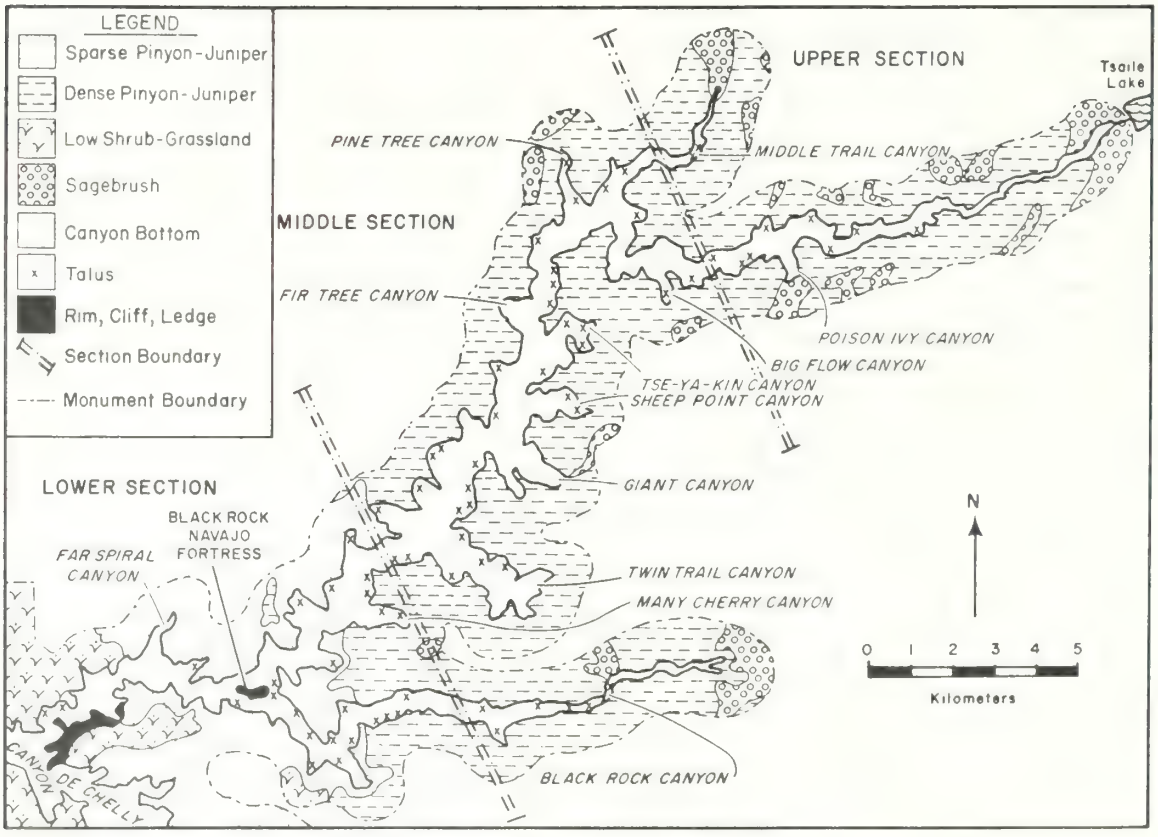

FIGURE 2. Canyon del Muerto topography and vegetation.

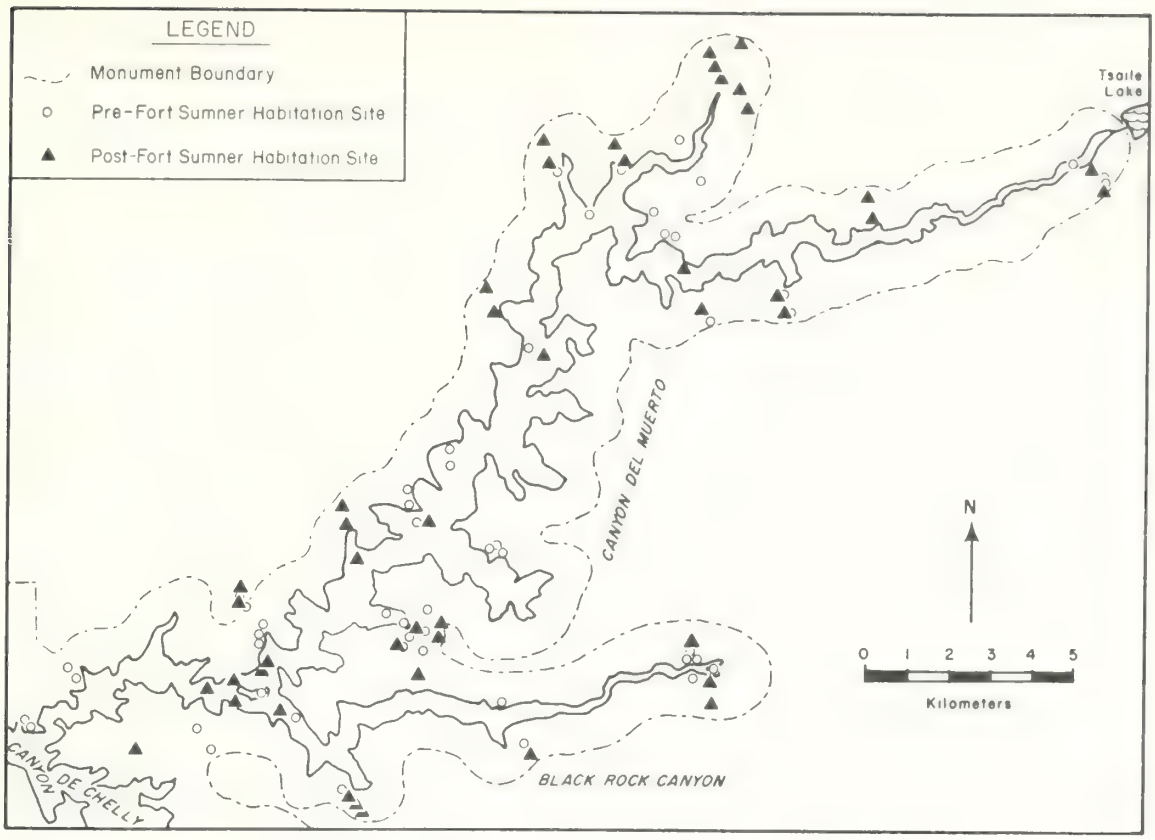

FIGURE 3. Canyon del Muerto Navajo habitation sites.

Sumner. After the return from Fort Sumner, the old defensive requirements would no longer be necessary due to the elimination of warfare; whereas, previously, defensive strategy such as the need for camouflage and access to places of refuge would have significantly affected settlement patterns.

Aside from the cessation of warfare, the most important effect of the Fort Sumner experience on the Navajo was their acquisition of a taste for American products. The drastic disruption of the subsistence system in the 1860's resulted in a dependence, first, on the ration center at Fort Defiance some forty miles to the southeast and, later, on the trading posts at the mouth (Chinle) and the head (Tsaile) of the canyon. The changing transportation system after Fort Sumner provided increased accessibility to the trading posts through the development of a road system and the introduction of wagons and later trucks.

An attempt to integrate the three factors of subsistence, defense, and transportation into a model of Navajo settlement strategy results in the following expectations:

> Prior to Fort Sumner one would expect a seasonally differentiated pattern of settlement significantly affected by defense needs. During spring and summer, habitation sites would be near arable land in the canyon. However, since arable land consists of broad stretches of alluvial bench which are extremely open and poor defensively, hogans would be situated in more protected cliff, talus, and rim locations adjacent to the farm land. During winter, sites would be found in the lightly wooded areas up on the plateau where there would be wood resources, camouflage, and nearby pasture. Open valleys and plateau grasslands would be avoided. After the return from Fort Sumner, these defensive requirements would no longer stand in the way of settlement in the open farm and pasture lands. The presence of the trading posts at both ends of the canyon and the transportation needs would encourage occupation of areas in the eastern and western portions of the area and away from the rough rim country.

The expectations of the settlement strategy model are fulfilled quite well. Pre-Fort Sumner canyon habitation sites are in protected areas--73% in rock shelters and 18% on talus slopes, with only one site on the open alluvial bench land. These sites are camouflaged further by their architectural style which involves masonry walls of untrimmed sandstone slabs and boulders. The defensive character of several habitation sites dating before Fort Sumner is quite clear. The outstanding example of this is the refuge site of Black Rock Navajo Fortress. This site is located on a butte isolated from the plateau by a deep cleft. Access to the top is by means of a trail up the face which involves traverses along narrow ledges, toe-and-hand-hold trails, and log ladders. On top of the butte are at least 49 stone-walled hogans, as well as a water reservoir, storage structures, and 22 crescent-shaped defensive walls along the ciff edge (Figure 4).

In contrast to the protected, camouflaged character of sites prior to Fort Sumner, Post-Fort Sumner sites are in the open. Ninety percent of these sites are on the alluvial benches adjacent to the farm lands. Architectural styles involve wooden hogans (forked-stick, cribbed-log,

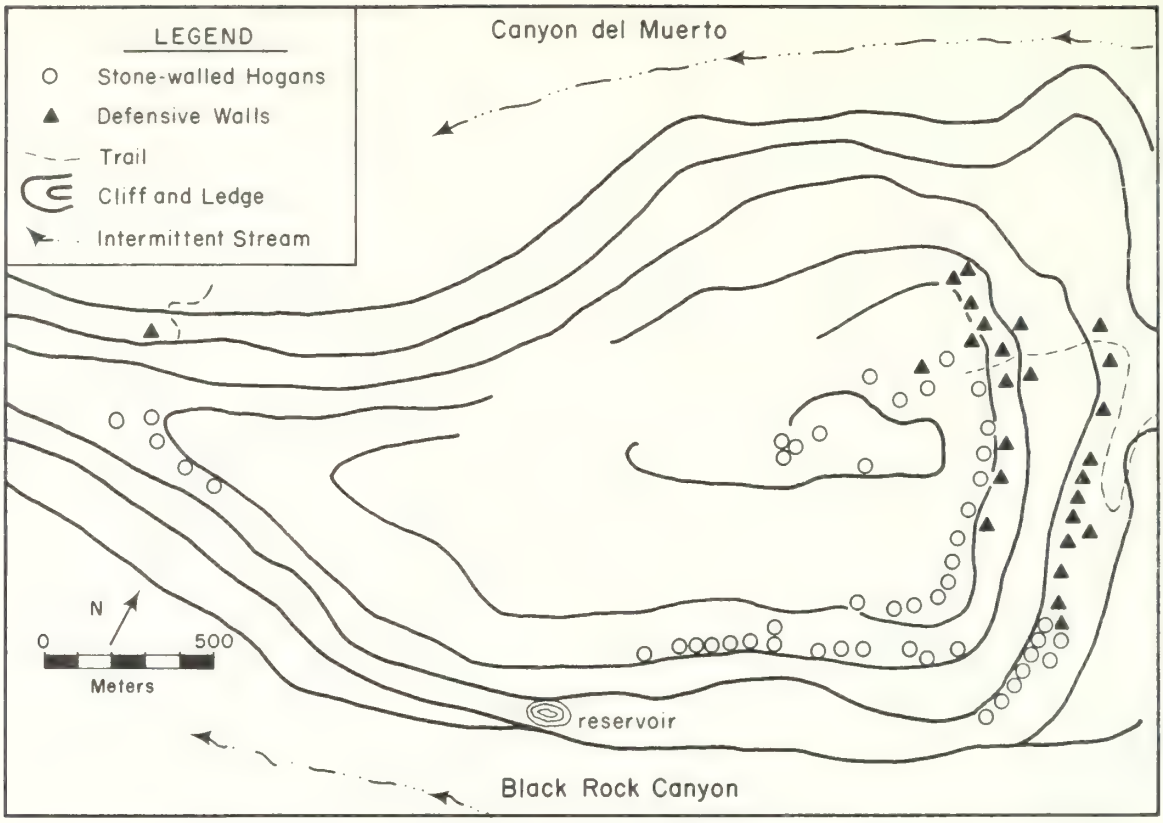

FIGURE 4. Black Rock Navajo Fortress refuge sites.

and many-legged types), trimmed masonry houses, and modern frame houses. Increasingly since 1960 these canyon sites have been relegated to weekend farming loci rather than summer-long habitation sites.

The settlement model predicted a closer association of Post-Fort Sumner sites with the prime farm land in the eastern portion of the canyon. The data indicate that 90% of the Post-Fort Sumner sites are within this region, while only 55% of the Pre-Fort Sumner sites are so located. The narrow side canyons, largely lacking in arable land but providing more defensive potential in their ruggedness and inaccessibility, were shunned completely by Post-Fort Sumner peoples; whereas, 25% of the Pre-Fort Sumner sites are found in these small canyons.

On the plateau, Post-Fort Sumner sites are located on the average more than twice as far from the canyon rim as Pre-Fort Sumner sites. Mean distance to the rim for sites prior to Fort Sumner is 376 meters as opposed to 813 meters for sites after Fort Sumner. The rugged rim with its sandstone ledges provided excellent camouflage for the largely stone-walled hogans of the period prior to Fort Sumner, but this country is too rough for the Post-Fort Sumner population, which was more concerned with good pasture and accessibility to the trading posts. Although favored site locations throughout the sequence remain ridges, 37% of the Pre-Fort Sumner sites are on protected ledges, canyon rims, and sheltered drainages, as opposed to only 6% of the Post-Fort Sumner sites. In contrast, 39% of the Post-Fort Sumner sites are on the open plateau or in open valleys, as opposed to only 16% of the Pre-Fort Sumner sites.

TABLE 1. Number of hogans per site for the pre-Fort Sumner and post-Fort Sumner periods in Canyon del Muerto.

Number of Hogans	Pre-Fort Sumner sites		Post-Fort Sumner sites	
	Number	Percent	Number	Percent
1	37	57	41	55
2	14	22	20	27
3	5	12	9	12
4	2	3	2	3
5	1	2	2	3
6	1	2		
7	1	2		
9	1	2		
10	2	3		
49	1	2		

The grasslands are located predominantly on the western half of the plateau around the mouth of the canyon. Therefore, pastoral peoples would be expected to favor the western sector. As expected, the western portion of the plateau accounts for 85% of the Pre-Fort Sumner settlement. However, the transportation requirements of the settlement model suggest that plateau settlement after the return from Fort Sumner would shift closer to the trading posts, toward the head of the canyon and toward the mouth on the north rim. Examination of site locations reveals that this shift does indeed occur, leaving the central portion of the plateau less heavily occupied than formerly. The current settlement on the north rim is concentrated in the nucleated settlement called Del Muerto Community, located near the junction of del Muerto with de Chelly. The trading post at the head of the canyon is no longer functioning, but the eastern plateau draws cattle ranching families who are engaging in extensive juniper chaining to clear artificial grazing land for their cattle.

The plateau sites over time become larger and more dispersed, although the mean number of hogans per site decreases from 2.8 in Pre-Fort Sumner times to 1.7 after Fort Sumner (Table 1). The more concentrated settlements in the earlier period would have been more defensible than the spread-out, open sites of more recent times.

The foregoing summary of the results of data analysis indicates that the predictions of the model regarding changes in settlement over time in the canyon and plateau are generally fulfilled. Thus, Navajo habitation site location strategy in Canyon del Muerto between 1750 and 1863 may be viewed as an attempt to reconcile the divergent needs of subsistence and defense. In contrast, between 1868 and 1970, herding and agricultural requirements and accessibility of trading posts interact to affect settlement decision-making.

LITERATURE CITED

BRUGGE, DAVID M. 1965. Long Ago in Navajoland. Navajoland Publications Series 6. Navajo Tribal Museum. Window Rock.

JAMES, CHARLES D., III and ALEXANDER J. LINDSAY, JR. 1973. Ethnoarchaelogical Research at Canyon del Muerto, Arizona: A Navajo Example. Ethnohistory 20(4):361-374. Tempe.

HESTER, JAMES J. 1962. Early Navajo Migrations and Acculteration in the Southwest. Museum of New Mexico Papers in Anthropology No. 6. Albuquerque.

LITTELL, NORMAN M. 1967. Proposed Findings of Fact in Behalf of the Navajo Tribe of Indians in Area of the Overall Navajo Claim. Docket 229. 6 volumes. Window Rock.

MATSON, DANIEL S. and ALBERT H. SCHROEDER. 1957. Codero's Description of the Apache--1796. New Mexico Historical Review 32:335-356. Albuquerque.

REEVE, FRANK D. 1960. Navajo-Spanish Diplomacy, 1770-1790. New Mexico Historical Review 25(3):200-235. Albuquerque.

THOMAS, ALFRED B., ed. 1932. Forgotton Frontiers: A Study of the Spanish Indian Policy of Don Juan Bautista de Anza, Governor of New Mexico 1777-1787. University of Oklahoma Press. Norman.

WALKER, JOHN GEORGE and O. L. SHEPHERD. 1964. The Navajo Reconnaissance: A Military Exploration of the Navajo Country in 1959. L. R. Bailey, ed. Westernlore Press. Los Angeles.

NEW INTERPRETATIONS OF CANYON DE CHELLY PREHISTORY
SUMMARY OF THE ANTELOPE HOUSE PROJECT

Don P. Morris[1]

INTRODUCTION

This paper will briefly summarize findings of the Antelope House Project, Canyon de Chelly National Monument, Arizona, with respect to prehistoric social organization, subsistence, and growth and abandonment of the site.

Early work in de Chelly developed a good basic chronology and indicated the existence of extraordinarily well-preserved materials within the numerous cliff dwellings and shelters of the area. Little research had been done recently and this project was designed to provide new information as the 80-room pueblo was developed for interpretation.

Antelope House is located in a large rock shelter on the floor of Canyon del Muerto, about 5 km from its junction with Canyon de Chelly. These canyons slash through the flanks of the Defiance Plateau as it descends from the 3000-meter high pine and spruce forests of the Chuska Mountains to the grasslands of the Chinle Valley. Pinyon-juniper forests, with occasional sagebrush clearings, grow over the majority of the plateau. The canyons provide a series of relatively wet environments in a generally arid region. The Navajo consider the canyon superior farm land and practice maize agriculture there with conspicuous success.

Since many of our research interests required environmental data, which was surprisingly sparse for a National Monument, studies of the present environment were incorporated from the beginning. These resulted in the first study of the modern fauna of Canyon de Chelly (Burgess 1973); a taxonomic plant study, which nearly tripled the number of species known to occur in the monument (Halse 1973), and the first plant community study of the area (Harlan & Dennis 1975).

I would like to first discuss the basic chronology of Antelope House, as it is basic to the discussion of our more important findings. Like so many sites in the canyon, Antelope House is deeply stratified. The earliest remains from the site are two Basketmaker III pithouses, built about AD 700. These were succeeded by an extensive Pueblo I village, constructed about AD 825. The community on which our investigation focused was begun in Late Pueblo II times, about 1050. The Pueblo III period, beginning in 1100, is divided into three periods, which can be considered valid only locally (Morris 1975:35). The periods, defined on the basis of major construction events at the site, are Early Pueblo III, 1100 to 1140; Middle Pueblo III, 1140 to 1200; and late Pueblo III, 1200 to 1270.

This chronology is based on the room construction sequence, on some 350 tree-ring dates and on eight archeomagnetic dates. Despite their impressive number, many of the tree-ring dates are from highly eroded fireplace charcoal, which is of relatively little value for dating (Morris 1975).

SOCIAL ORGANIZATION

Our study of the social organization at Antelope House attempted to specify the number of social units present at the site during late Pueblo III times. We concluded that two such units existed at the site, one of which was older and may have controlled more of the available resources.

By "social unit" we mean a group of people who performed a wide range of activities together and who had a conscious feeling of attachment to the unit. The model employed for analysis assumes that individuals cooperating in an activity will share concepts, techniques and motor skills with each other more frequently than with others. Archeological data will retain evidence of some of these; those techniques which are transmitted unconsciously within the group will most clearly indicate the presence of the group in the archeological data. A further assumption for Antelope House is that the material recovered, most of which is trash or secondary refuse, lies in the approximate area used by the group.

Inspection of the site map suggests that inhabitants of the rooms to the north might comprise a social unit distinct from the unit occupying the southern rooms. Several architectural features supported this hypothesis, including relative room size, kiva wall art and the restriction of multi-story architecture to the South Room Block.

Examination of the artifacts recovered from these areas tended to confirm this distinction. Row numbers of corn recovered from the south differ significantly from those of contemporaneous deposits in the North Room Block (Hall 1975). Technological variables within the large basketry collection, such as coil size, stitch length and splice type, and utility ceramic attributes, such as temper, angle of indentation of corrugations and indentation style, all cluster on a north-south basis (Adovasio & Gunn 1975; Thornton n.d.).

Architecture, utility ceramics, maize and basketry, therefore, demonstrated significant variation between the north and south portions of the site; textiles and sandals did not (Magers n.d.) and decorated ceramics, which included many traded pieces, were inconclusive (Schaeffer n.d.).

If this analysis is correct, room blocks at Antelope House, and, by extension, at other Pueblo III sites in Canyon de Chelly, would correspond to social units within the sites. Most of the larger Pueblo III sites in the canyon, such as Mummy Cave and Sliding House, consist of two room blocks separated by open space or by construction which is non-domiciliary in nature. Nothing like the circular Central Plaza is known elsewhere in the canyon, however.

GROWTH AND ABANDONMENT

Having isolated two contemporaneous groups at Antelope House, it is instructive to compare their histories. The construction of the site began about 1050 and was confined to what became the South Room Block. At approximately 1140

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construction activity increased markedly, with the building of multi-story units in the south and the initiation and rapid development of the North Room Block. This correlated with abandonment of sites on the plateau and with the onset of drier weather locally, according to unpublished research by the Laboratory of Tree-Ring Research at the University of Arizona. Their finding is supported by the decline of phreatophytes in the trash at this time. The social organization of Antelope House was influenced, but not entirely shaped, by environmental change which encouraged population concentration near water sources. The population of the site was very high during this period, either slightly higher or lower than the Late Pueblo III period, which saw an upswing in precipitation.

Abandonment of the de Chelly area and of much of northern Arizona occurred after the onset of a drought in the mid-1270s, but Antelope House was deserted slightly earlier, probably no later than 1270.

The abandonment of the site at a time of abundant rainfall suggests that flooding or its effects may have caused the abandonment. Photographs of Antelope House taken in the late nineteenth century show that the present erosion damage had occurred by then. While definitive dating of this event will require a study of the alluvium of the canyon, there is some evidence for placing this erosion early. No Navajo period strata are bisected by the erosion and Navajo use within the site is well away from the unstable erosion edge. The latest prehistoric floors are bare, with no usable artifacts remaining. Roof timbers had been thoroughly and systematically removed, suggesting that the inhabitants moved no great distance from the site or that other groups were present nearby at the time of abandonment.

SUBSISTENCE

The importance of "corn, beans and squash" in the prehistoric Southwest has been recognized for years. Other foods are often viewed as supplemental or as "starvation" diets. Encouraged by the variety and abundance of preserved vegetal material, we investigated the nature of subsistence and diet at Antelope House and its changes through time (Fry & Hall 1975). Our eventual aim was to assess the nutritional adequacy of the diet, but for a variety of reasons this proved unfeasible.

Data relating to diet are derived from two major sources: (1) from plant and animal remains found within the site, as discarded refuse, in stored caches or as artifactual material, and (2) from human feces, which were generally well preserved and distributed throughout the site.

Each of these sources is susceptible to significant bias in interpretation. Fecal analysis provides the most informative data, but present techniques do not accurately reflect the amount of meat consumed, because of its more complete digestion. Fecal data, therefore, emphasized vegetal foods over meat. Although remains of a plant species which is consumable by humans may be recovered from trash, this finding does not mean that the plant was consumed, much less that it was consumed on a regular basis.

A wide variety of foods was consumed, particularly uncultivated plant species. Seventeen major plants were detected in human feces, as were several bizarre substances, such as grasshoppers and turkey eggs (Fry & Hall 1975). All 17 were also present in the vegetal refuse.

Two-hundred-twenty-four of the 647 plant taxa known from de Chelly are biologically edible, according to our search of the ethnobotanical literature; about a third (78) occur in the archeological record at the site. The plant communities, or major subdivisions thereof, in which these species occur should indicate areas which were more intensively collected. We find that the likelihood that a plant will occur in the archeological deposit at Antelope House increases as the plant becomes more widespread in the monument; the most exploited zones are those closest to Antelope House, with no data to suggest distant gathering or exchange with groups living closer to sagebrush and upper canyon rim areas, the two least-used zones. The canyon bottom, in general, provides more biologically edible plants than do any of the other areas, a factor which would tend to concentrate canyon populations during times of stress. Useful plants are not limited to the canyon floor, however; the surrounding plateau was exploited regularly.

Fecal analysis demonstrates that maize was the most commonly consumed vegetal food, occurring in 92% of the examined samples. The enormous quantity of cobs, seeds and stalks, as well as the abundant pollen recovered from metates and from the interiors of utility pottery, support this conclusion (Bryant & Morris n.d.). The second most common vegetal food is cactus, occurring in 55% of the samples. Squash and pine nuts were the third most common at 29%, followed by cottonseed, 18%, beeweed, 15%, and amaranth, 12%. Beans were found in only one specimen; although present in the trash, they are relatively rare (Fry & Hall 1975).

The wild and semi-cultivated plant species obviously were not neglected. There is no suggestion that one species or another was a starvation food. The extensive use of gathered foods indicates that agriculture added to food resource but that little was relinquished from earlier dietary patterns.

Variability within the dietary data suggests that changes in consumption might mirror the availability of wild foods, revealing climatic correlations. A factor analysis (Gunn 1975) demonstrates that such variability is not present and that the diet was remarkably constant through time. All variations produced by the factor analysis can be more economically explained by sampling error than by real dietary fluctuation.

COTTON CULTIVATION

At one time it was believed that cotton was not grown within Canyon de Chelly and that textiles retrieved from the ruins were trade items from the south. It is difficult to find the basis for this belief in the recent literature, but the statement is found several times in the monument's interpretive program.

Cotton is commonly found in deposits at Antelope House in several forms: as seeds, raw lint, bolls and spun yarn. Weaving was a significant activity at the site. Each of the four Late Pueblo III kivas contains at least one set of loom anchors. Various weaving tools are present in the assemblage. Over 1300 textile fragments were recovered from the site, providing about half of the total textiles available for study from the entire Southwestern U. S. (Magers 1975).

In view of these data, it is difficult to maintain that cotton was not grown in the area. We attempted to grow native cotton in various localities, producing fiber from a plot at Monument Headquarters. Although the growing season at

Canyon de Chelly is somewhat marginal for cotton (146 frost free days), judicious selection of microenvironments with sunny warm exposures yields growing seasons significantly longer than average.

The quantity of textiles recovered from Antelope House contrasts with the eight textiles recovered from comparable excavations at Mug House, Mesa Verde National Park (Rohn 1971). No seeds, lint or bolls were observed at Mug House, although excavation techniques employed there should have detected them had they been present. It is worthwhile to hypothesize that textiles at Antelope House may have been produced, in part, for trade to areas to the north and east, such as Mesa Verde. The sharp increase in cotton remains and kiva looms at Antelope House after 1200 may reflect one consequence of increased integration and communication among the Anasazi population of the Four Corners area.

LITERATURE CITED

ADOVASIO, J. M. and J. GUNN. 1975. Basketry and Basketmakers at Antelope House. The Kiva 41 (1).

BRYANT, V. M. and D. P. MORRIS n.d. The functional use of ceramic vessels recovered from Antelope House, Arizona: The pollen evidence.

BURGESS, T. L. 1973. Mammals of the Canyon de Chelly Region, Apache County, Arizona. Jour. Arizona Academy of Science 8 (1):21-25.

FRY, G. and H. J. HALL. 1975. Human coprolites from Antelope House: Preliminary analysis. The Kiva 41 (1).

GUNN, J. n.d. A descriptive analysis of coprolite data from Antelope House: In Excavations at Antelope House. Natioal Park Service.

HALL, R. L. n.d. Cultivated plant species: In Excavations at Antelope House. National Park Service.

HALSE, R. 1973. The flora of Canyon de Chelly National Monument. Unpublished M.A. thesis. University of Arizona.

HARLAN, A. S. and A. E. DENNIS. 1975. The wild plant remains. The Kiva 41 (1).

MAGERS, P. C. 1975. The cotton industry at Antelope House. The Kiva 41 (1).

MAGERS, P. C. n.d. Technical and behavioral analysis of vegetal artifacts: In Excavations at Antelope House. National Park Service.

MORRIS, D. P. 1975. Architectural development and masonry style at Antelope House. The Kiva 41 (1).

ROHN, A. D. 1971. Mug House, Mesa Verde National Park, Colorado. National Park Service Archeological Research Series 7-D.

SCHAEFFER, J. I. n.d. Decorated and unfired ceramics: In Excavations at Antelope House. National Park Service.

THORNTON, B. n.d. Utility ceramics analysis: In Excavations at Antelope House. National Park Service.

PREHISTORIC SETTLEMENT PATTERNS IN CANYON DE CHELLY NATIONAL MONUMENT

James A. McDonald[1]

Canyon de Chelly National Monument is located within the Navajo Reservation in northeast Arizona. It is noted for its deep canyons and numerous prehistoric villages. The prehistoric occupation of Canyon de Chelly National Monument by people of the Anasazi culture has been the subject of research since the 1870s (McDonald 1976: 18-31). Archeological surveys have been conducted by the Bureau of American Ethnology (Stevenson 1886; Mindeleff 1897; Earl Morris 1925; A. A. Morris 1933; David de Harport 1959; Jon Young 1971; James E. Mount (unpublished); V. K. Pheriba Stacy and Don P. Morris 1972; and Charles James 1972, 1974a-i). Largely through the work of Earl Morris (1925, 1938, 1948), the monument has become a classic locality in Southwestern archeology. In spite of the long history of research and numerous surveys, archeological survey data available prior to 1973 were inadequate for many management and research purposes. The Canyon del Muerto Survey was initiated to meet some of the most pressing management and research needs.

Previous archeological research within the monument had concentrated on spectacular Anasazi cliff and rock shelter villages within the canyons. Lack of information about the archeology of the plateau above posed acute management and research problems. Surveys on the plateau included a reconnaissance of the south rim of Canyon de Chelly near the canyon's mouth by David de Harport (1959:61-62), a survey of the alignment of the Spider Rock Overlook Road (Young 1971), surveys of alignments for overlook roads on the north rim of Canyon del Muerto (Stacy and Morris 1972) and a reconnaissance of the north rim of Canyon del Muerto by Charles James (James 1972). The effectiveness of the reconnaissances as archeological inventories of the surveyed areas and the respresentativeness of the road alignment surveys as samples of the plateau sites were open to question. This meant that the monument was not in compliance with Executive Order 11593 and 36-CRF-800 and that assessment of the impact of park development during early stages of planning was impossible. The Bureau of Indian Affairs Land Office was then supporting a program of pinyon and juniper clearance through chaining on the plateau. Since the Navajo retail full use rights to monument land and since monument boundaries are not marked on the plateau, areas within the monument were chained; the resulting loss of archeological resources was difficult to estimate.

Analyses of material from the Antelope House Project also indicated the need for an archeological survey for research purposes. Earlier surveys of the monument had not gathered data in a number of areas necessary to assess the accuracy of the Antelope House analyses and the extent to which they could be generalized to the monument as a whole. Fecal analyses, for example, indicated a far greater dietary significance for certain wild plants, such as cacti, than had previously been supposed (Fry et al. 1975). It was felt that the accuracy of this conclusion could be tested through survey and proved through the discovery near concentrations of such plants of sites containing tools for gathering and processing the plants (Morris and Rock 1975:18-19). The representativeness of the Antelope House results was to be tested through the analysis of fecal specimens collected from other sites during the survey (Morris and Rock 1975:22).

Research and management concerns thus coincided and plans for a representative sample survey of Canyon del Muerto were formulated and approved (Rock 1975; Morris and Rock 1975). We decided to focus survey efforts on this portion of the monument, since it had not previously been inventoried and since it was believed to contain data more directly relevant to questions raised by the Antelope House research. The survey was not designed to inventory the canyon, but to sample it in a systematic, representative manner, allowing the results to be generalized to unsurveyed areas for the solution of research problems and for the assistance of management in the initial stages of planning for development or in formulating resource management plans. The survey may be extended to other portions of the monument in the future. Field work began with a reconnaissance in 1974 (Hall and Rock 1974). Intensive survey began in 1975 and continued during 1976. Additional work is planned for 1977. Both systematic transect and systematic quadrat sampling schemes have been employed. Approximately 6% of Canyon del Muerto and the adjacent plateau have been surveyed and over 400 sites have been recorded, ranging in age from Basketmaker II to recent Navajo hogans. This paper will discuss survey findings to date about the prehistoric occupation of the plateau.

In order to do this, it is necessary to briefly describe the flora of Canyon del Muerto. During the Antelope House Project the plant species present were inventoried and classified into seven "plant resource groups." A resource group is defined as an area containing one or more plant communities and requiring distinctive methods of exploitation (Dennis 1975). The resource groups include Canyon Bottom Communities, Talus Communities, Spring and Seep Communities, Low Shrub-Grassland Communities, Sagebrush Communities, Canyon Rim, Cliff and Ledge Communities and the Pinyon-Juniper Continuum. Four of these resource groups occur on the plateau: Low Shrub-Grassland, Sagebrush, Canyon Rim and the Pinyon-Juniper Continuum. The most prominent plants in the Low Shrub-Grassland Communities are rabbitbrush (*Chrysothamnus nauseosus*), snakeweed (*Gutierrezia sarothrae*) and galleta grass (*Hilaris jamesii*). This group covers 7% of the plateau. Sagebrush (*Artemisia tridentata*) dominates the Sagebrush communities, accounting for over half of the vegetative cover. This resource group covers 13% of the plateau. Prominent plants of the Canyon Rim resource group include sagebrush (*Artemisia bigelovii*), mountain mahogany (*Cercocarpus* sp.), juniper (*Juniperus osteosperma*), pinyon pine (*Pinus edulis*), shrub oak (*Quercus turbinella*) and Gambel oak (*Quercus gambelii*). This group covers less than one percent of the plateau. The most prominent plants in the Pinyon-Juniper Continuum are pinyon pine and juniper, accounting for up to 60% of the ground cover. It is called a "continuum" because it has been subdivided into "sparse," "medium" and "dense" stands, which increase gradually in density with increasing elevation. This resource group covers 79% of the plateau.

One of the objectives of the Canyon del Muerto Survey has been to determine whether Anasazi

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archeological sites are randomly distributed with respect to these plant resource groups. If different resource groups required different kinds or methods of exploitation, one might expect variation in the number, area or types of sites present, The specific nature of any such departures from randam distribution might indicate the utilization of specific resources within the group and might, in turn, be used to test hypotheses concerning Anasazi subsistence. Finally, the discovery that sites were non-randomly distributed with respect to the plant resource groups would provide park management with estimates of site numbers and site types within easily definable environmental units.

Sixty-eight Anasazi sites have been recorded on the plateau. Thirty-two are sherd and lithic scatters, 24 are artifact scatters with hearths, cists or other small surface features and 12 have traces of pithouses or masonry rooms. The majority of the sites appear to be single-component and to have been occupied for no more than 100 years, in contrast to some of the canyon sites, which show up to 900 years of continuous occupation. Although none of these sites have been excavated, comparison of surface artifacts and features with those on sites on the north rim of Canyon del Muerto excavated by the Museum of Northern Arizona in 1972 (James 1974a-i) suggests that the two sets of sites are similar. Of the nine sites excavated by James, two had no subsurface features, four had hearths or firepits and three had one to four pithouses. James interpreted the sites as seasonally occupied camps, used sometime during the spring, summer or fall. Winter habitations were believed to have been in Canyon del Muerto.

Of the 68 sites recorded by the Canyon del Muerto Survey, 55 were located in the Pinyon-Juniper Continuum, 11 were found in the Canyon Rim plant resource group, two were found in Sagebrush communities and none was found in the Low Shrub-Grassland group. Assuming that the number of sites in a given plant resource group should be proportional to the area of that group if sites are distributed without respect to plant groups, a chi-square test was applied to survey data on site locations and the hypothesis of randomness was rejected at the .05 level (x^2 = 166.7, df = 3). The results, although significant, should be viewed with some caution because of a low expected number of sites in the Canyon Rim cell of the table (.68). However, the results do suggest a lower than expected number of sites in Sagebrush and Grassland and a higher than expected number of sites in the Canyon Rim resource group. A somewhat different pattern emerges if one assumes that the percentage of aggregate site area (the total area of the recorded Anasazi plateau sites) in a given resource group should b proportional to the percentage of plateau land covered by that plant resource group. Ninety-two percent of the aggregate Anasazi site area is located in the Pinyon-Juniper Continuum, which covers 79% of the plateau; one percent is located in the Canyon Rim plant resource group, which covers one percent of the plateau; six percent is located in Sagebrush resource groups, which covers 13% of the plateau area, and no sites are found in Low Shrub-Grassland, which covers 7% of the plateau. Again, the utilization of Sagebrush and Grassland is less than expected. However, this procedure suggests that the expected amount of site area is located in Canyon resource groups and indicates a preference for occupation of the Pinyon-Juniper Continuum.

The plant resource groups, as defined by Dennis, contain characteristic associations of topographic and climatic conditions, as well as plant associations. This complicates the task of explaining non-random distributions of Anasazi sites with respect to resource groups, since the Anasazi may have been selecting for environmental characteristics other than the plant species present. This seems to be the case with regard to the higher than expected number of sites in the Canyon Rim plant resource group. In addition to its characteristic plant species, the Canyon Rim group contains numerous small rock shelters suitable for habitation and storage. Ten of the 11 sites in this group are located in such shelters. The shelters are small, with a mean area of about 75 m^2 in the case of the occupied shelters, and this probably accounts for the rather small total area of the Canyon Rim sites (occupied shelters do not seem to differ in size from unoccupied shelters, based on informal observations by survey personnel).

Explanation of the larger than expected number of sites in the Canyon Rim plant resource group appears to be fairly straightforward, but the multiplicity of environmental variables which characterize each plant resource group complicate explanation of the apparent Anasazi preference for occupation of the Pinyon-Juniper Continuum. Two hypotheses are being investigated: the Anasazi may have been farming the land encompassed by the continuum or they may have been gathering a resource found primarily within the continuum.

The first hypothesis is suggested by the common assumption that the Anasazi were primarily dependent upon agriculture for subsistence and by the fact that the Pinyon-Juniper Continuum receives more rainfall than Low Shrub-Grassland groups, a factor frequently associated with greater agricultural potential in the Southwest. In this regard, it should be pointed out that the two sites recorded in Sagebrush resource groups appear to receive amounts of rainfall equal to those in the Pinyon-Juniper Continuum. The smaller than expected number of sites in Sagebrush groups might be due to soil characteristics, the difficulty of clearing sage, the fact that clearing pinyon and juniper would provide fuel and construction timber, which clearing sage would not, or to use of the sage flats as fields but not as habitations.

The second hypothesis is suggested by analyses of Antelope House fecal specimens (Fry et al. 1975) and by ethnographic data (Steward 1938; Broman 1973). The fecal analyses indicated that pinyon nuts were an important component of the Anasazi diet: fragments of pine nuts occurred in 29% of the fecal specimens (Fry et al. 1975:12). Pinyon nuts have high food potential and have been a staple for many Southwestern societies. A pound of nuts can supply nearly all daily nutritional requirements for an average individual between the ages of 20 and 45 who does not work hard (Broman 1973:9). Thus it may be hypothesized that Anasazi sites in the Pinyon-Juniper Continuum were pinyon gathering stations. In this regard, it should be noted that the two sites located in Sagebrush groups are also located on the borders of large stands of pinyon and juniper. The Low-Shrub-Grassland plant resource group lacks large stands of pinyon or any other plant resource used by the inhabitants of Antelope House in similar quantities (Ambrose 1975a).

While evidence suitable for testing either hypothesis is limited, the identification of the Anasazi sites as pinyon gathering stations is favored. While the greater precipitation in the Pinyon-Juniper Continuum might foster an Anasazi preference for farms in that resource group, it does not adequately account for the apparent absence of sites in the Grassland resource group. Farming is possible in that group, as demonstrated

by the existence of Navajo fields in such areas. However, the possibility of sampling error as a reason for the absence of sites cannot yet be ruled out. A second reason for favoring the identification of Anasazi sites in the Pinyon-Juniper Continuum as pinyon gathering stations is the fact that the continuum's greater precipitation is a mixed blessing. The increased precipitation is due to greater elevation and is accompanied by a shorter growing season, creating a greater risk to agriculture. In fact, corn agriculture in the Anasazi area generally was practiced below 6500 feet elevation (Gilman 1976:15), while all but two Anasazi plateau sites are above 6600 feet. Finally, the plateau sites excavated by James (1974a-i) have revealed a number of unique features, including globular, unlined pits approximately one meter wide at the mouth and one to 1.5 m deep, with recesses in one corner, usually the northwest. The recesses contained fire areas and the pits usually had ash and charcoal in their fill. Similar pits have not been noted in contemporary sites within the canyons, suggesting that the pits were used in some activity unique to the plateau, possibly the roasting of pinyon cones to extract the nuts. Excavation of additional sites and botanical analyses of pit contents to test this hypothesis are being considered for the future.

A second pertinent pattern is also evident in the Canyon del Muerto Survey data: there appears to have been a marked decline in use of the plateau after AD 1150. On the basis of their ceramic assemblages, five sites appear to have been occupied prior to AD 850. These have a total area of 6777 m^2, or 11% of the aggregate area of dated plateau sites. Seven sites appear to date from about AD 850 to 1050, with a total area of 43,228 m^2, or 67% of the aggregate dated site area. Sixteen sites were occupied from approximately AD 1050 to 1150, having a total area of 38,239 m^2, or 60% of the aggregate dated site area. Only four sites, with a total area of 5609 m^2, or 9% of the aggregate dated site area, appear to have been occupied after AD 1150. (Some sites were occupied during the transition between periods, and were counted twice, thus, percentages sum to more than 100%.) This is a sharp decline from the preceding period and contrasts with the situation within Canyon del Muerto, where a decline in population does not seem to have occurred until at least AD 1250 (Don P. Morris 1976; per. comm.). The decline might seem to have begun after AD 1050. However, the sites of the period from AD 850 to 1050 are the least reliably dated; four sites, with an aggregate area of 14,928 m^2, could be earlier or later than indicated.

The decline in use of the plateau after AD 1150 correlates with climatic changes inferred from tree-ring analyses (Robinson and Dean 1969) and from Antelope House botanical analyses (Ambrose 1975b). These analyses indicate that a prolonged, severe drought was experienced in northeastern Arizona from AD 1140 to 1180. This drought may have reduced yields of pinyon nuts on the plateau and forced the Anasazi to rely increasingly on the resources of the canyon bottom, where the water supply is more reliable. It appears that use of the plateau did not increase following AD 1180. The Antelope House botanical analyses again suggest a reason. While climatic conditions improved following AD 1180, they apparently did not match those from 1050 to 1150, a period characterized by increasing average annual rainfall and including one 20-year period of above-average rainfall (Schoenwetter and Eddy 1964:98-107; Robinson and Dean 1969:7; Ambrose 1975b:123-128). Thus the Anasazi seem to have lost a component of their subsistence system. This may have placed the Anasazi in a rather precarious position with respect to their food supply when the climate deteriorated again during the latter part of the 13th century and suggests avenues of investigation for explaining the Anasazi abandonment of the monument at that time. This is a topic of recurrent interest to archeologists working in the monument.

Future analyses of the Canyon del Muerto Survey data will focus on the investigation of these suggestions. Questions to be asked include:

Does the population of the canyon show a marked increase following AD 1140? This occurred at Antelope House, but we are not sure that it is true of the entire canyon. Such an increase would create the potential for exceeding the productive capacity of the canyon.

If a sharp increase occurred after AD 1140, did the population continue to increase following the initial spurt of growth? Such conditions would further increase the likelihood of the population exceeding the productive capacity of the canyons.

Do signs of stress occur when environmental conditions again deteriorated in the latter part of the 13th century? Agricultural intensification, increased reliance on wild resources or reliance on a greater variety of wild resources might suggest that traditional subsistence methods were not yielding enough food to provide for the canyon population.

Finally, how do abandonment dates correlate with the onset of deteriorating environmental conditions and indications of stress in the subsistence system?

While this paper has dicussed the Canyon del Muerto Survey results primarily in research terms, benefits for management also are apparent. Survey results which suggest the number and types of sites in the plant resource groups can be used in early stages of development project planning to estimate impacts on archeological resources. The distribution of the resource groups is illustrated on a series of 7½' USGS topographic maps. If development of a specific area is proposed, planners can consult these maps and determine that the area is within, for example, the Low Shrub-Grassland resource group, and can obtain an idea of the archeological resources apt to be encountered; in this case, the probability of finding Anasazi sites appears to be extremely low. However, Magers (1976) indicates that the chance of encountering Navajo sites is rather high and provides information which could be used to estimate their age, size and architectural features. These data would also be useful in estimating mitigation procedures and costs. In those areas actually surveyed, the data would be adequate for the preparation of an environmental impact statement. In other areas an inventory survey would ultimately be necessary, but the representative sampling strategy of the del Muerto survey gives greater assurance of reliability to estimates made using its data during initial project planning stages.

When complete the Canyon del Muerto Survey, together with the Antelope House Project, will provide a unique record of the relationship between a prehistoric people and their natural environment. The more than two metric tons of vegetal material recovered at Antelope House are not equaled at any other excavated Southwestern site and have provided detailed information on the diet and environment of its inhabitants. The Canyon del Muerto Survey will enable archeologists to assess the representativeness of the Antelope House data

with respect to the entire canyon and will provide information on changes in population size and settlement pattern correlated with changes in subsistence and environmental conditions. This is an opportunity that should not be missed by park interpreters, an opportunity to obtain and to present information that is not available at any other park or monument in the Southwest. It is my feeling that interpretive programs in the Southwest too often stress culture history at the expense of discussing the unique aspects of individual parks. The Antelope House Project and the Canyon del Muerto Survey offer the chance to break that pattern.

LITERATURE CITED

AMBROSE, JAMES E. JR. 1975a. Plant resources of Canyon de Chelly National Monument. On file, Western Archeological Center, Tucson. Xeroxed.

_____. 1975b. The past environment of Canyon de Chelly. On file, Western Archeological Center, Tucson. Xeroxed.

BROMAN, CATHERINE 1973. Aboriginal uses of the pinyon pine. On file, Western Archeological Center. Xeroxed.

DE HARPORT, DAVID L. 1959. Archaeological survey of Canyon de Chelly, northeastern Arizona; a Puebloan community through time. Unpublished Ph.D. dissertation, Department of Anthropolgy, Harvard University.

DENNIS, ARTHUR 1975. The natural vegetation of Canyon de Chelly National Monument. Kiva 41(1):15-22.

FRY, GARY F., H. JOHNSON HALL and JOEL GUNN 1975. Human coprolites from Antelope House. On file, Western Archeological Center, Tucson. Xeroxed.

GILMAN, PATRICIA 1976. Walnut Canyon National Monument: an archeological overview. Western Archeological Center Publications in Anthropology 4.

HALL, ROBERT L. and JAMES T. ROCK 1974. Canyon del Muerto study photographic reconnaissance. On file, Western Archeological Center, Tucson. Xeroxed.

JAMES, CHARLES D. III 1972. Preliminary report for excavations of historic and prehistoric sites NA11,361 through NA11,379 and NA11,549 through NA11,551: spur roads 1 through 4, north rim, Canyon del Muerto, Canyon de Chelly National Monument, Arizona. On file, Museum of Northern Arizona, Flagstaff. Xeroxed.

_____ 1974a. Preliminary report for archaeological excavations, prehistoric site NA11,363-Ariz. E:15:22 (MNA) - CDM 92, spur road 3. On file, Museum of Northern Arizona, Flagstaff. Xeroxed.

_____ 1974b. Preliminary report for archaeological excavations, prehistoric site NA11,364-Ariz. E:15:23 (MNA) - CDM 93, route N64, spur road 3. On file, Museum of Northern Arizona, Flagstaff. Xeroxed.

_____ 1974c. Preliminary report for archaeological excavations, prehistoric site NA11,365-Ariz. E:15:24 (MNA - CDM 94, route N64, spur road 3. On file, Museum of Northern Arizona, Flagstaff. Xeroxed.

_____ 1974d. Preliminary report for archaeological excavations, prehistoric site NA11,376-Ariz. E:15:9 (MNA) - CDM 107, spur road 1. On file, Museum of Northern Arizona, Flagstaff. Xeroxed.

_____ 1974e. Preliminary report for archaeological excavations, prehistoric site NA11,378-Ariz. E:15:27 (MNA) - CDM 111, spur road 4. On file, Museum of Northern Arizona, Flagstaff. Xeroxed.

_____ 1974f. Preliminary report for archaeological excavations, prehistoric site NA11,379-Ariz. E:15:25 (MNA) - CDM 112. On file, Museum of Northern Arizona, Flagstaff. Xeroxed.

_____ 1974g. Preliminary report for archaeological excavations, prehistoric site NA11,550-Ariz. E:15:29 (MNA) - MUC-2, spur road 4. On file, Museum of Northern Arizona, Flagstaff. Xeroxed.

_____ 1974h. Preliminary report for archaeological excavations, prehistoric site NA11,551-Ariz. E:15:30 (MNA) - MUC-3, route N64, spur road 4. On file, Museum of Northern Arizona, Flagstaff. Xeroxed.

_____ 1974i. Preliminary report for archaeological excavations, prehistoric site NA9720-Ariz. E:12:1 (MNA) - CT-11. On file, Museum of Northern Arizona, Flagstaff. Xeroxed.

MAGERS, PAMELA C. 1976. Navajo archeology in Canyon del Muerto: the historic study of the modern inhabitants of Canyon de Chelly National Monument, Arizona. Paper presented at the First Conference on Scientific Research in the National Parks, New Orleans.

MCDONALD, JAMES A. 1976. An archeological assessment of Canyon de Chelly National Monument. Western Archeological Center Publications in Anthropology 5.

MINDELEFF, COSMOS 1897. The cliff ruins of Canyon de Chelly, Arizona. Bur. Am. Ethnology Ann. Rep. 16:73-198.

MORRIS, ANN AXTELL 1933. Digging in the Southwest. Doubleday, Doran & Co.

MORRIS, DON P. and JAMES T. ROCK 1975. Canyon del Muerto research design. On file, Western Archeological Center, Tucson. Xeroxed.

MORRIS, EARL H. 1925. Exploring in the Canyon of Death. Nat. Geo. 48(3):263-300.

_____ 1938. Mummy Cave. Nat. Hist. 42(2):127-138.

_____ 1948. Tomb of the Weaver. Nat. Hist. 52(2):66-71, 91.

ROBINSON, WILLIAM J. and JEFFREY S. DEAN 1969. Tree-ring evidence for climatic changes in the prehistoric Southwest. Laboratory of Tree-Ring Research, Tucson.

ROCK, JAMES T. 1975. The Canyon del Muerto study. Paper presented at the 1975 meeting of the Society for American Archaeology, Dallas.

SCHOENWETTER, JAMES and FRANK W. EDDY 1964. Alluvial and palynological reconstruction of environments, Navajo Reservoir District. Mus. N. M. Papers in Anthro. 13.

STACY, V. K. PHERIBA and DON P. MORRIS 1972. Archeological survey of four spur roads, Canyon de Chelly National Monument, Arizona. On file, Western Archeological Center, Tucson. Xeroxed.

STEVENSON, JAMES 1886. Ancient habitation of the Southwest. Bull. Am. Geo. Soc. 18:329-342.

STEWARD, JULIAN H. 1938. Basin-plateau aboriginal sociopolitical groups. Bur. Am. Ethnology, Bull. 120.

YOUNG, JON N. 1971. Spider Rock overlook road. On file, Western Archeological Center, Tucson. Typescript.

ATLATL CAVE: ARCHAIC-BASKETMAKER II INVESTIGATIONS IN CHACO CANYON NATIONAL MONUMENT

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Our search for the beginnings of agriculture in Chaco Canyon began with an intensive site survey covering 43 square miles. We found 2220 sites, and 94 of them were lithic sites from the Archaic and Basketmaker II culture-periods. Most of these sites were on sandy ridges overlooking the canyon floor. They contained scatters of chipped stone, and occasionally cobble manos, basin metates, burned sandstone, and distinctive projectile point types. We excavated small portions of two of these sites in August 1975 and June 1976.

Atlatl Cave (29SJ1156) is a small sandstone rockshelter with characteristic Basketmaker II paintings on the back wall including a triangular, broad-shouldered man. The cave deposits are shallow, about 25cm thick, and in two summers of field work we've excavated about 55% of the total fill. We found two distinct cultural components and the remains of several wood rat houses.

In the center of the shelter we found a fossil wood rat house superimposed upon a Basketmaker II trash midden. Only the lowest stratum of the midden was not disturbed by mixing from the wood rat occupation. Charcoal from the disturbed upper deposit and the undisturbed lower deposit yielded C-14 dates of 950-910 B.C. -82 years. We found characteristic Basketmaker II remains including corn, beans, squash, a broken atlatl, a yucca fiber sandal, several kinds of small seed beads made from juniper, *Ephedra* and Gromwell seeds, hematite pigment, fragments of rabbit fur fabric, coiled basketry, and no pottery, no turquoise, and no Pueblo projectile point types. We did not find burials, storage cists and a few other things usually found at Basketmaker II cave habitation sites.

We studied the plant material from the wood rat house and found a wealth of information regarding the local vegetation three thousand years ago. Twigs, bark, leaves and seeds from juniper, pinyon and Douglas Fir indicate that the plant community in the rincon (small side canyon) was once dominated by woodland species. Today the surrounding area is an arid grassland. The nearest Douglas Fir tree is thirty miles away and several hundred feet higher. The nearest pinyon-juniper woodland is several miles upstream on Chacra Mesa.

The midden contained a large number of seeds brought in by the prehistoric occupants, both human and pack rat, We found corn, beans, squash, yucca, pinyon, juniper, skunkbush, chokecherry, hackberry, Indian rice grass, prickly pear cactus, wildrice, sunflower, four-wing saltbush, sand verbena, mountain privet, wild lettuce, tarweed, crownbeard, poison ivy, mountain mahogany, bladderpod, aster, goldenrod, thistle, four o'clock, beardgrass and muhly. Most of these species are still found in the Chaco Canyon area; a few such as hackberry are not.

In the northern end of the shelter we found a pack rat midden, including large masses of "amberat" (dried urine), which sealed off an isolated Archaic midden. We found several San Jose type projectile points made from non-local materials including obsidian from the Jemez Mountains, New Mexico, and Alibates chert from Texas. We found thousands of small mammal bones and a few large mammal bones including bison and human bones. Charcoal in the midden was C-14 dated at 2900 B.C. $\pm$136 years.

Atlatl Cave faces a large sand dune with two small lithic concentrations on it (29SJ1157). We dug a number of test trenches through the two areas and found an abundance of chipped stone, a hearth, a basin metate, cobble manos, numerous knives, drills and late Archaic (Basketmaker II) projectile point types.

Atlatl Cave is not an ideal habitation site. It is too small. Even a single family would find the quarters cramped. The Basketmaker people who visited the cave probably spent most of their time in the campsite on the adjacent dune, when they weren't out hunting rabbits and harvesting plant foods.

This excavation has been important to us for several reasons. 1) It is the oldest habitation site we've excavated in Chaco Canyon. 2) It has given us a chance to look at a relatively undisturbed Basketmaker II occupation site. 3) It has given us a chance to look at some perishable remains such as fabrics and wooden objects. 4) It has given us dates for domesticated plants in Chaco Canyon, and the dates are earlier than expected. 5) It has shown us the value of analyzing the plant remains in ancient wood rat houses and middens.

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STRANGE BEDFELLOWS? TANGENT POINTS OF IN-PARK CULTURAL AND NATURAL RESOURCES RESEARCH

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It is evident to visitors and scientists alike that most National Park Service areas contain both natural and cultural resources in some combination and association. Each resource base calls for the application of different management attitudes, different approaches to legal compliance, different research strategies, and different stewardship principles. This paper will focus on aspects of mutual concern or "tangent points" between the biological, physical, archaeological, and historical spheres of interest of scientists from different disciplines. But this paper is also biased since it is a viewpoint from a perspective which deals with prehistoric and historic archaeological materials as cultural resources. Only those "tangent points" of archaeology with other disciplines will be discussed. I recognize that there are many similar points between other fields of science.

About half of the Western Region's 35 major park areas, as of Fall 1976, have finished or nearly finished either natural, cultural, or combined resource management plans. Other plans are in earlier stages of preparation. From 18 plans, an analysis of similarities shows that cultural or natural resource plans have three basic proposals:

A. Inventories of known or observable data, sometimes coupled with interpretations;

B. Corrective measures to bring resources closer to an acceptable standard;

C. Control measures to prevent or slow deterioration of resources.

If these are commonalities of both cultural and natural resource research and management plans, where are the possible conflicts among sciences or potential resolutions to multi-resource management problems?

Inventory and interpretive studies--whether they are of plants or animals, of archaeological sites, or older buildings, soil types, or tide pool invertebrates--are usually non-destructive. Only the current condition of the resource is described and if specimens are taken, the effects of removal can be mitigated by standard field recording procedures. Such basic resources data may be shared and used by different researchers, with consultation. Inventory studies, then, are building blocks upon which other actions--research or management or both--may be built.

Corrective measures such as restoration of fire as a natural process, reduction of exotics, restoration of native life forms, or stabilization of structural elements, are done to bring the resource closer to a defined standard. This standard may be "the primeval setting" of a natural area, or the authentic appearance of an historic structure, or the integrity of an archaeological site. But actions such as these often have built-in effects on multiple resources since the desired end product is change.

Control measures are designed to continue the state achieved during a corrective measure, or to monitor an effect, or to prevent an impact. Fences or access controls use levels based on carrying capacity studies, re-routing of human and animal traffic are examples of such measures. Some of these actions may involve adverse or beneficial impacts on resources.

Here is the first tangent point between disciplines--that control and corrective actions are likely to impact more than one type of resource simultaneously with a variety of effects. An awareness of this on the part of all scientists is not only commonplace professional courtesy but may have direct, valid relationships to a) legal compliance, b) avoidance of errors in data interpretation, and c) to the development of more productive research designs. Some examples of corrective or control measures from recent Western Region plans which considered a variety of resource impacts are the following:

1. At Joshua Tree National Monument, the construction of guzzlers for bighorn sheep involved archeological clearances since sites are often clustered near desert water holes;

2. In Death Valley, a five-year monitoring of burro impacts on archeological sites near water sources and trails is part of a burro management plan;

3. Within Grand Canyon, consideration of archeological materials was included within a burro management study;

4. At Point Reyes Seashore, effects of controlled burns on surface stone artifacts and fossil pollen were considered.

5. In City of Refuge National Historic Park, Hawaii, the increased visibility of historic ruined structures as resulting from removal of exotic brush was discussed.

But some plans do not contain such perceptive considerations. Perhaps when questions of muliple-impacts are raised, the need for considerations of *all* resources will seem clear when control or corrective measures are developed by scientists, park staffs, or both groups.

Low cost but useful projects designed to document presence or absence of impacts from multi-resource plans should be accomplished. The concept of a combined cultural and natural resources management plan as a vehicle for interdisciplinary research planning may be unfamiliar to persons outside of the Western Region but such combined plans have been prepared for some Arizona park areas and Death Valley. Although criticisms of such plans have been voiced from Washington, multi-resource impacts are effectively illustrated in these combined plans.

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A second tangent point between scientific circles ought to be stressed although it is commonplace between some researchers--the use of data from counterpart disciplines. Certainly, the Service has actively pursued this attitude during the Mesa Verde Park research projects. Archeological work may provide a zoologist or botanist with data on duration of speciation processes, on former range of endangered genera or species, or on the morphological evolution of life forms over measured time. Using soil flotation techniques or dated pollen spectra from buried cultural deposits, former vegetation zones or plant communities can be reasonably delineated in time and space. Where understanding of primeval conditions and of natural successional processes are goals for natural resource management, use of paleoecological data from some types of archeological resources would be necessary. Of course, archeologists have consistently used other specialists to identify excavated bone, plant or mineral materials but there are other means to effectively use such data sources. In the preparation of National Register nominations, for example, archeologists should use the kinds of data found in recent specialists' reports (if available) for environmental descriptions or significance statements, rather than rest only on their own observations. The kinds of data produced by natural scientists useful to archeologists are primarily inventory in scope. Soils maps, vegetation maps or biotic zones maps as existing data may relate to environments at a contact time or prehistoric time period or throughout a succession of time units. Computer analyses of both biological and archeological distributional data may yield a very different view of a park's environmental history than that described from one discipline only. For increased efficiency of research designs by different scientists in these times of tight dollars, greater use of complementary data from companion sciences should be done.

In realms of both cultural and natural values, the possible evolution of park areas as resource enclaves or remnants seems real in some geographic regions. Cultural resources--especially historic and prehistoric archeological sites--in semi-arid areas or near urbanized centers may not, as yet, be affected by expanding human use by virtue of their status as legislated preserves. Endangered natural resources as relic populations have also been identified within many park areas. Neighboring private or other governmentally held lands may or may not enjoy environmental protection via legislation. Even though other Federal lands fall under Congressional and Executive Order preservation mandates, they possess different land use histories with respect to recreation, timber harvest, or hunting. Thus, impacts on such lands' natural and cultural values have been greater. Older park areas in densely populated regions may be further along the process of becoming enclaved. Both natural and cultural resource investigators should be aware that the enclave process does not always affect only the other fellow's resources. If this process is real--and it appears to be--both types of resources take on a heightened importance *together* as associated phenomena within a particular piece of terrain. This concept of diminishing resources constitutes the third tangent point between natural and cultural science disciplines.

The last aspect of mutual concern is composed of similarities in stewardship or management directions. From the standpoint of a park manager, Hawaii Volcanoes Superintendent Robert Barbee's recent comments are worthy of emphasis (Barbee 1976). Earlier this year, Barbee discussed three attitudes which he felt park managers should keep in mind when addressing natural resources--Bob said:

> Avoid simplistic answers to complex ecological problems.
> Think in terms of *processes*, rather than *objects*.
> Use latest scientific knowledge and data when proceeding with a problem.

Bob's very appropriate suggestions for other managers can be aimed at cultural resources too, which are no less complex and are non-renewable. Paraphrased, Barbee's remarks would read as follows:

> Avoid simplistic answers to problems of cultural resource management.
> Cultural resources, as are natural resources, also *illustrate processes* and are not simply objects.
> As disciplines change and grow, use the latest professional data and approach as the most appropriate to a problem.

In a June 16, 1976 memorandum, Deputy Director William Briggle stated to Regional Directors that no new Service-funded research projects may be undertaken unless identified in an approved Resources Management Plan. Research for planning purposes could only be undertaken if identified in an Outline of Planning Requirements document, Briggle noted. Thus, a conservation approach to both types of resources as well as to Service funds means that a research project--including archeological--may not occur whether within the Service or by an outside contractor unless previously identified.

Specialists in both cultural and natural resource management units are now assisting park managers with suitable data and proposals but the specialists should also provide yearly updates by means of existing procedures. After all, both natural and cultural resource specialists have similar goals and should therefore strengthen their own interdisciplinary contacts with administration personnel. One type of yearly update could be the development of short but well-designed projects to test impacts on counterpart resources. Effects of ground fire on archaeological materials, changing visibility of ruined structures or surface artifacts after removal of exotic vegetation, impact of changes in human or animal traffic patterns, or changes in rodent or insect habitat as older buildings are removed or rehabilitated--all of these actions could be easily tested by local trials.

Although the category scheme of natural, historical, and recreational areas of the Park System may be "of limited usefulness as a guide to management decisions" (1975 NPS Management Policies, page IV-1), each area has its distinctive legislative guidelines, *even though* a variety of resources are present. Cultural and natural resource management and research plans contain implicit and explicit interdisciplinary concerns which are also localized frameworks for management actions to enable staffs to conform with Service policy and park establishment law.

Archaeologists and natural scientists working in park areas need to do several things in order to broaden their viewpoints and increase the efficiency of Park Service research programs. In summary, I believe we should do at least four things:

1. Recognize and test the multi-resource impacts of proposals as contained within management plans, especially the corrective and control types of actions;

2. Increase the use of complementary data already produced by other disciplines,

particularly in analytical formats;

3. Adopt the conservation position toward research through the programming process and in the formation of manager attitudes since some parks' resources may become--or may be already--unique as remnants;

4. Use research guidelines as expressed by the professional community--such as the Airlie House papers--to better implement NPS compliance and management policy.

If archaeologists and natural scientists are strange bedfellows now, let us lie in a bed of roses rather than a bed of thorns.

LITERATURE CITED

BARBEE, ROBERT D. Manager's Perspective: The Conceptual Basis for Natural Resource Management in the National Park System. Read at the first Biennial Conference in Natural Sciences, May 1976, Hawaii Volcanoes National Park.

BRIGGLE, WILLIAM J. Natural Science Programs and Resource Management Plans. Memorandum to Regional Directors, June 16, 1976.

NATIONAL PARK SERVICE Management Policies 1975. Department of the Interior, Washington.

STEPS AND TRAILS IN THE GLEN CANYON AREA

Natalie B. Pattison[1]

INTRODUCTION

The area with which this study is concerned is the portion of the Colorado River called Glen Canyon by John Wesley Powell during his explorations in 1869 and 1872. Today the impoundment of water behind Glen Canyon Dam inundates the canyons and glens which prompted the name. Lake Powell lies primarily in southern Utah with a small but important tongue in northern Arizona. It is a lake in a relatively barren land, characterized by the deep canyons, steep-sided cliffs, mesas, and plateaus of the southwestern canyonlands country.

In 1956 there was initiated one of the most diversified emergency salvage programs undertaken up to that time. This research was continued until 1963 when the gates of the dam were closed and the lake began to fill. The anthropological portion of the project was conducted primarily by two contractors, the University of Utah, and the Museum of Northern Arizona. It is to the personnel of these institutions that I am indebted for much of the information basic to my own research: Jennings (1966); Long (1966); Adams, Lindsy, and Turner (1961); Crampton (1969, 1962, 1964a, 1964b); Lister (1958); Fowler, et al. (1959); Sweeney and Eyler (1963); Euler (1966); and Lipe, et al. (1960). J. Frank Wright, E. Tad Nichols, and L. D. Potter contributed their time as well as their knowledge of the area history and the physical aspects of the river and lake shores.

In 1971 several institutions were awarded grants from NSF-RANN to investigate the impact of man's activities in the Lake Powell region. Research was supported by grants NSF-RANN GI-34831 and NSF-AEN 72-03462 AO3 to the Shoreline Ecology Subproject. This particular paper is Contribution No. 49 of the Lake Powell Research Project Contribution Series.

ANASAZI "MOQUI STEPS"

While participating in the lakeshore ecology subproject of the University of New Mexico, I became especially interested in the shoreline features popularly known as "moqui steps." Moqui steps are hand and toe holds pecked with stone tools by prehistoric peoples into the soft sandstone to facilitate access into use areas where such access is difficult. They are by no means restricted to the Lake Powell or the Glen Canyon area--pecked steps are often found in the Southwest where the substrate is soft enough for such a chipping technique. The distinctive thing about the Glen Canyon steps, and the more elaborate trails, is that these routes have been so fully and intentionally utilized by groups who succeeded these prehistoric Anasazi in the canyon.

Anasazi is the term applied to peoples of the Southwest who occupied certain geographical and cultural areas in the Four Corners Region from about A.D. 1 to the time of the Spanish entry in 1540, with considerable flexibility in the earlier date. The Anasazi in the Glen Canyon area are included in the Kayenta Branch which flourished primarily in what is today northeastern Arizona. It appears that their occupation of the canyon was primarily to exploit the natural resources, especially in terms of farming the deep alluvial soils in several of the side canyons. Occupation may have been seasonal and was certainly fluctuating. House and storage units were built on the level tops of talus slopes or in the natural shelters and overhangs found in the Navajo, Kayenta, and Wingate sandstone outcrops. Toe and hand holds led to these domestic structures and to potholds where water was stored at certain seasons of the year. Longer series led up or down the cliffs to the broad terraces which served as the highways of the canyon.

The sandstones in Glen Canyon exhibit a differential weathering pattern which results in the formation of relatively broad terraces in the Carmel and Kayenta sandstones. The canyonlands area may appear extremely difficult to traverse, but to the Anasazi, with his knowledge of the terrain, the combination of the foot trails up the steep cliffs and the broad terraces made it possible for him to travel with relative ease. It is these trails which were adapted and utilized by succeeding groups although, except for the Paiute, their environmental exploitation of the area was vastly different.

PAIUTES AND NAVAJOS

By A.D. 1250 in Glen Canyon, as in the rest of the Kayenta region, much of the area was abandoned in favor of locations with a more permanent water situation. Euler (1966) includes in the aboriginal Southern Paiute territory the Glen Canyon region of southern Utah and northern Arizona. These people were foragers, and undoubtedly ranged widely throughout this former Kayenta Anasazi country but there is little evidence of their use of a trail system. However, in late historic times, Paiute sites are intermingled with Navajo. One cannot state with authority that the Navajo became the primary user of at least the lower area of the canyon until 1850.

The Navajo probably entered the canyon during the Indian Wars of 1846-1870 (Crampton 1959), and by 1890 their hogans were appearing on the benches and alluvial flats of the area bordered today by the Navajo Reservation. Following, in many instances, the same pathways as had the Kayenta Anasazi, the Navajo changed and adapted these trails for use as sheep driveways, often cutting platform steps immediately adjacent to the toe and hand holds. Remnants of the log and stone ramps and barriers constructed along these trails can still be seen on the canyon walls above the present lake level.

MINERS, MISSIONARIES, AND CATTLEMEN

From 1892 to about 1903 a gold rush brought miners into the San Juan and Glen Canyon areas. Utilizing, for example, a prehistoric foot trail at California Bar they enlarged the steps to football size in order to climb out over the steep cliff wall to the easily traversed Carmel platform above. These particular adaptations were obviously never intended for the use of animals. However, beautifully and meticulously cut stairs, as seen

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at Klondike Bar, were used for bringing horses or burros in and out of the mining areas along the river bars. A more roughly-cut "horse ladder," with evidence of prior use, provided access to a gaging station in the bottom of the Escalante River canyon.

The famous Dominguez-Escalante Expedition of 1776 brought missionaries looking primarily for a way to cross the river. Mormon and Gentile ranchers pastured their cattle on the Kayenta bench in the upper canyon and today Navajo cattle travel over the Carmel terrace in the West Canyon area to a paradise of plentiful water. These trails follow the same circuitous routes as did the Anasazi in order to reach the highlands from the water sources.

The steps and trails of this area are a major legacy to the National Park Service for its interpretation of shoreline features in the Glen Canyon National Recreation Area. The Anasazi chipping sites are gone; most of the domestic and storage structures are gone; many of the pictograph and petroglyph panels are gone; the Navajo hogans and corrals are gone; the mining machinery lies rusted beneath the lake. These footholds and trails remain as tangible evidence for the occupation of Glen Canyon and the utilization of its resources.

LITERATURE CITED

ADAMS, W. Y., A. J. LINDSAY, JR., and C. G. TURNER II. 1961. Survey and excavations in lower Glen Canyon, 1952-1958. Mus. of Northern Arizona Bull., No. 36, Glen Canyon Ser., No. 3. Flagstaff.

CRAMPTON, C. G. 1960. Historical sites in Glen Canyon, mouth of San Juan River to Lee's Ferry. Univ. of Utah Anthropol. Papers, No. 46, Glen Canyon Ser., No. 12. Salt Lake City.

CRAMPTON, C. G. 1962. Historical sites in Glen Canyon, mouth of Hansen Creek to mouth of San Juan River. Univ. of Utah Anthropol. Papers, No. 61, Glen Canyon Ser., No. 17. Salt Lake City.

CRAMPTON, C. G. 1964a. Historical sites in Cataract and Narrow Canyons, and in Glen Canyon to California Bar. Univ. of Utah Anthropol. Papers, No. 72, Glen Canyon Ser., No. 24. Salt Lake City.

CRAMPTON, C. G. 1964b. The San Juan Canyon historical sites. Univ. of Utah Anthropol. Papers, No. 70, Glen Canyon Ser., No. 22. Salt Lake City.

EULER, R. C. 1966. Southern Paiute ethnohistory. Univ. of Utah Anthropol. Papers, No. 78, Glen Canyon Ser., No. 28. Salt Lake City.

FOWLER, D. D., J. H. GUNNERSON, J. D. JENNINGS, R. H. LISTER, D. A. SUHM, and T. WELLER. 1959. The Glen Canyon archeological survey, parts I and II. Univ. of Utah Anthropol. Papers, No. 39, Glen Canyon Ser., No. 6. Salt Lake City.

JENNINGS, J. D. 1966. Glen Canyon: a summary. Univ. of Utah Anthropol. Papers, No. 81, Glen Canyon Ser., No. 31. Salt Lake City.

LIPE, W. D., F. SHARROCK, D. DIBBLE, and K. ANDERSON. 1960. 1959 excavations, Glen Canyon area. Univ. of Utah Anthropol. Papers, No. 49, Glen Canyon Ser., Salt Lake City.

LISTER, R. H. 1958. The Glen Canyon survey in 1957. Univ. of Utah Anthropol. Papers, No. 30, Glen Canyon Ser., No. 1. Salt Lake City.

LONG, P. V., JR. 1966. Archeological excavations in lower Glen Canyon, Utah, 1959-1960. Mus. of Northern Arizona Bull., No. 42, Glen Canyon Ser., No. 7. Flagstaff

SWEENEY, C. L., and R. C. EULER. 1963. Southern Paiute archeology in the Glen Canyon drainage: a preliminary report. Nevada State Mus. Anthropol. Papers, No. 9. Carson City.

OCMULGEE NATIONAL MONUMENT: PERIPHERAL SITES TUFT SPRINGS #1 (13Bi25) AND #2 (13Bi19)

James W. Stoutamire[1]

Included in National Park Service repositories is a large quantity of scientifically valuable archeological material collected from within park boundaries or by WPA personnel and now under Service jurisdiction.

Florida State University maintains the Southeast Archeological Center (SEAC) laboratory for the National Park Service. The University's responsibilities include the curation of the collections (cataloging and accessioning collections and restoring, repairing, and preserving both artifactual and archival materials) and researching old and new collection components. As part of that research program it is essential to critically examine each collection component to determine its suitability for research based on collection condition, note condition, scientific value, and value to Park Service goals. After some 40 years of neglect, it is obvious that not all of the collections remain in usable condition nor do they all retain relevant information by current standards.

During the past several years we have concentrated research on the WPA excavations in and around Ocmulgee National Monument in order to produce a series of reports and, eventually, a Macon Plateau and Ocmulgee River Basin archeology. As part of this ongoing research effort, the Tuft Springs #1 and #2 sites were analyzed as representatives of a time period previously unreported. The analysis of the Tuft Springs #1 (13Bi25) and #2 (13Bi19) sites was undertaken under the terms of contract CX500060788 under the direction of Dr. James W. Stoutamire (Stoutamire et al. 1976). Dr. Stoutamire was responsible for overall project direction and writing the report sections dealing with excavation methodology and site stratigraphy and analysis conclusions. Three MA candidates from the Department of Anthropology, Florida State University, conducted the analysis of the material and were responsible for specific portions of the collections. Chad O. Braley analyzed the faunal and human remains, Thomas R. Gest analyzed the lithics, and Patricia A. Logan analyzed the ceramics.

Note should be made here that the original work at these sites was done in 1937 and 1938 at a time when archeological problems and standards were not the same as they are today. Given that the excavation methodology of 1937 and 1938 was not the same as today, we should note that analysis of this material is still important for three reasons:

1) Recent quarry activity has totally destroyed both sites and the surrounding terrain.

2) Research in this area has only poorly defined the Late Archaic (2000-1000 B.C.) Phase of occupation.

3) Analysis of sites in this geographic area and specific time period will be of use to the interpretive program at Ocmulgee National Monument and of importance as a guide for future research.

We were fortunate in that the artifact collection was in generally good condition with few if any missing items. The only artifacts to suffer badly from the passage of time were the human remains which were in poor condition when excavated. The excavation notes (Willey n.d.) presented the largest analysis problem as the available notes were quite sketchy. Conversations with Gordon Willey, the excavator, and detailed study of the catalog record were helpful but did not entirely solve the problem. They, however, produce enough information for analysis to proceed to a successful conclusion. The lack of a complete key map of Tuft Springs #1 makes it impossible to locate the 1938 Stratigraphic Survey excavations, although the available map does locate the test pits around the mound and the cross trenches cut through the mound. The two Stratigraphic Survey pits were located on opposite sides of one of the 1937 cross trenches. We suspect, on the basis of the Stratigraphic Survey at other Macon area sites, that they were located close to the center of the mound in order to obtain maximum stratigraphic depth. Inconsistencies between the notes and the catalog cards with respect to the type of material recovered in a give unit were resolved in favor of the catalog since washed material would be easier to identify than unwashed material in the field.

SITE LOCATION

The Tuft Springs #1 site was located 3.32 miles south of the 5th Street bridge in Macon, Georgia and .4 miles east of a north/south line through that bridge (see Figure 1). The site consisted of a three-foot high mound 100 feet in diameter and the surrounding area. The immediate area is a flat marshy floodplain with the 1827 map of the first settlement of Macon showing a hardwood forest consisting of holly, poplar, hornbeam, white oak, beech, sweet gum, and elm (Brender 1970). This contrasts to the 1937 vegetation cover of swamp brush, cypress, gum and pine which reflects some 100 years of intermittent cultivation. Initial excavations in 1937 consisted of eight test pits around the mound which revealed little material indicating that the mound was essentially the total site. Therefore, north/south and east/west trenches five feet wide were cut through the mound. In 1938 the Stratigraphic Survey placed two 15 x 15 foot squares in the central area of the mound.

The Tuft Springs #2 site was located 2.57 miles south of the 5th Street bridge (see Figure 1) in similar terrain to that of Tuft Springs #1. Ten 5 x 10 foot test pits were excavated and revealed very thin deposits with no concentrations suggesting light habitation.

CERAMICS

The bulk of the ceramic remains studied in this report were recovered from the Tuft Springs #1 site in the two cross trenches and the two

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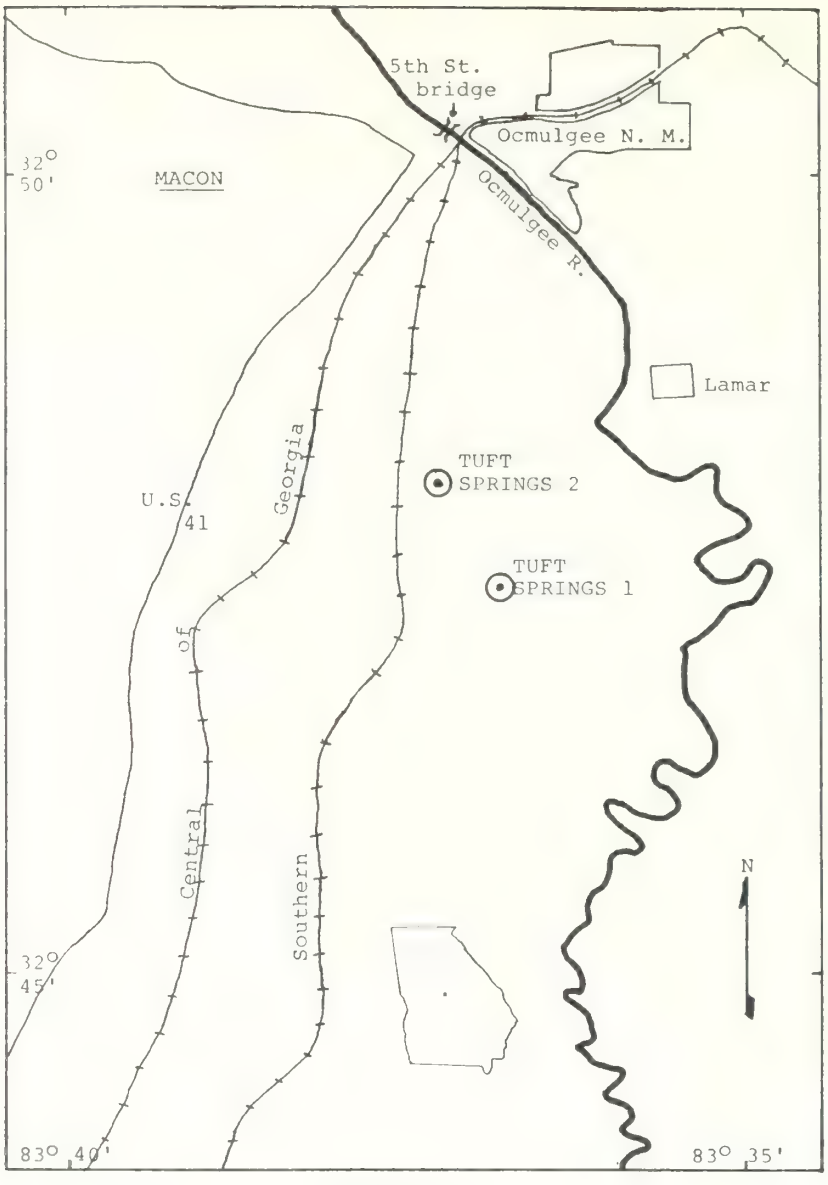

SITE LOCATION
FIGURE 1.

Stratigraphic Survey pits. The ceramics fall into three major categories. Fiber-tempered wares dating to the Late Archaic and consisting of two varieties of Stallings wares and several unidentified wares. Early Woodland Stamping tradition represented by such wares as Mossy Oak and Deptford. Complicated Stamp tradition covering the period from Middle Woodland through Proto-Historic and represented by such wares as Lamar, Swift Creek, and Napier. See Tables 1 and 2 for the ceramic counts from the two sites.

The ceramic data suggests that Tuft Springs #1 and #2 were temporary campsites occupied primarily in the Late Archaic but utilized, at least occasionally through the Late Mississippian. It is also suggested that Tuft Springs #1 was occupied slightly earlier than Tuft Springs #2.

LITHICS

The available lithic inventory is primarily from Tuft Springs #1, 2,307 artifacts of which 910 show indications of use, since few lithics were recovered at Tuft Springs #2, 235 of which only 16 exhibit indications of use. The most common lithic material utilized was chert (75% of the sample) with quartzite (12%), sandstone, and ochre accounting for the remainder.

Identifiable projectile points include Savannah River (15), Morrow Mountain (19), Lecroy (3), Dalton (Greenbriar variety, 5), Pine Tree (3), Small Appalachian (8), Sugar Creek (3), Cataco Creek (3), and Randolf (4). Twenty-five of the 93 projectile points exhibit evidence of heat treatment including glassy or greasy flake scars, a color shift, and pot-lidding.

Other major artifact categories include scrapers (side, ovoid, and stemmed) and knife blades. The bulk of the remaining lithic inventory is made up of chipping debitage. Unfortunately, it appears that as excavation proceeded there was increasing intentional selection of "keepers" as opposed to simple debitage thus making debitage analysis difficult. The only complete bannerstone recovered is similar to the Stanley type from the Hardaway site while the two

TABLE 1. Tuft Springs site #1; ceramic totals.

	Total	Percent
Plain fiber tempered	88	21
Decorated fiber tempered	5	1
Sand with fiber temper	18	4
Grit with fiber temper	12	3
Mossy oak	2	-
Deptford simple stamp	2	-
Deptford bold check stamp	2	-
Deptford linear stamp	26	6
Woodland cord marked	4	1
Napier complicated stamp	3	1
Etowah complicated stamp	4	1
Swift Creek complicated stamp	45	10
Lamar complicated stamp	38	9
Lamar incised	1	-
Lamar rim	3	1
Lamar plain	1	-
Unidentified complicated stamp	17	4
Folded plain rim	1	-
Plain sand tempered	86	21
Plain grit tempered	30	7
Plain rim	8	2
Unidentified	11	2
Steatite vessel fragments	13	3
TOTAL	420	100

fragments resemble ones recovered from the Eva site (Coe 1964; Lewis 1961). Eight grinding stones or slabs were recovered from Tuft Springs #1.

The bulk of the identifiable lithics are consistent with a Late Archaic/Early Woodland temporal placement of these sites although there are indications of some occupation during the earlier Archaic. Relative temporal placement of these two sites on the basis of the lithics is inconclusive. It was noted, however, that the lithic distribution exhibited a marked increase in raw quantities when comparing the central portion of the Tuft Springs #1 site with the margins.

FAUNAL REMAINS

Faunal remains were only recovered from the Tuft Springs #1 site (see Table 3). In contrast to the lithic distribution the faunal remains tend to cluster in the central portion of the site

Based on a simple total bone count there was a heavy utilization of deer in the time period by the deepest strata (36"-39"). This was followed by an immediate drastic decline (24"-36") and a gradual increase (12"-24") which does not quite reach the high initial level. A decline in remains was again evident in the upper two levels (6"-12", the 0-6" level was discarded). Butchering marks and the bone inventory indicate carcasses were jointed in the field and the skulls and midsections were left there.

Bone artifacts include deer ulna awls, antler handles, antler projectile point, antler scraper, and the base of an antler headdress.

HUMAN REMAINS

Human remains consist of four burials from Tuft Springs #1. Burial 1 was in poor condition due to plowing and could not be aged or sexed. Burial 2 was flexed, lying on its right side, with no grave goods. The individual was a female slightly over 50 years old. The long bones are

TABLE 2. Tuft Springs site #2; ceramic totals.

	Total	Percent
Plain fiber tempered	13	15
Decorated fiber tempered	10	11
Sand with fiber tempered	1	1
Grit with fiber tempered	14	16
Deptford bold check stamp	2	2
Woodland cord marked	1	1
Napier complicated stamp	1	1
Swift Creek complicated stamp	10	11
Lamar complicated stamp	2	2
Plain stamp tempered	19	21
Plain grit tempered	8	9
Plain rim	5	6
Steatite vessel fragments	3	3
TOTAL	89	100

no longer present in the collections so a height estimate is not possible. Burial 3 was in the same condition as Burial 1. Burial 4 was evidently a cremation, probably of a bundle burial. The indiviual was a 50 to 60 year old male.

CONCLUSIONS

Since quarry activity has destroyed both of these sites, it is difficult to determine their precise elevation. However, all of the available evidence indicates that they were located at or below the 280-foot contour. Therefore, both sites were subject to flooding an average of 60 times per 100 years. If they are at or below the 279-foot contour this flooding probably occurred quarterly. Since the 280-foot contour is some distance to the north, we suggest that these sites were at or below the 279-foot contour and were therefore flooded quarterly.

This flooding has a number of implications. First, frequent flooding would probably keep the soil wet or at least moist, thereby accounting for the lack of patination of the chert (Nelson et al. 1974:20) at both sites. Second, the excellent bone preservation at Tuft Springs #1 as opposed to other sites in the area may be partially due to the leaching of shells in the midden which lowers soil acidity and partially due to high soil moisture and rapid exchange of soil water lowering acidity. Note should be made that this assumes the soil rarely dried out as alternate periods of wet and dry cause rapid bone decay. Third, repeated flooding and a generally very wet swampy environment would make this area unattractive for permanent settlement unless large areas of dry land were available for habitation. With the elevation of the area it appears unlikely that large dry areas existed. On the other hand, riverine and land animal populations would make this an attractive hunting area. Tuft Springs #1 seems to have been initially located on a slight rise and would naturally have risen higher by midden deposition through time. Its small size argues against a permanent settlement but the mound elevation suggests the mound would provide a dry location during quarterly floods. The situation at Tuft Springs #2 is unclear but the lack of a mound suggests the site was probably flooded regularly with light occupation between floods.

Data used to formulate the temporal placement of the occupation of the Tuft Springs #1 and #2 sites are drawn from the ceramic and lithic studies discussed in detail in the complete site report (Stoutamire et al. 1976).

TABLE 3. Minimum number of individuals.

Mammals	
Beaver *Castor canadensis*	1
Deer *Odocoileus virginianus*	16
Dog *Canis familiararis*	3
Muskrat *Ondatra zibethicus*	1
Opossum *Didelphis marsupialis*	4
Raccoon *Procyon lotor*	3
Birds	
Turkey *Meleagris gakkopavo*	1
Other passerine birds (sp?)	11
Reptiles	
Turtle *Chrysemyl picta*	1
Other turtles (sp?)	19
Molluscs	
Clam *Elliptia hopetonensis*	105
Snail *Campeloma geniculum*	2

Tuft Spring #1 provides the most complete data. The relative frequencies of plain and decorated fiber-tempered ceramics from Tuft Springs #1 suggest an earlier original date of occupation than at Tuft Springs #2 as do two possible Poverty Point objects. The high percentage of fiber-tempered ceramics to the time period involved compared to those for later ceramics indicates more intense occupation during this time period than during subsequent periods. Light Early to Middle Archaic occupation is suggested by the Morrow Mountain, Lecroy, Dalton, Pine Tree, Guilford, and White Springs projectile points. The dominant point types are, however, typically Late Archaic/Early Woodland types such as Savannah River, Leaf-shaped, Small Appalachian, Limestone, Cotaco Creek, Greeneville, Frazier, and Elora. Thus the lithics and the evidence of lithic heat treatment (a Woodland trait) supports the hypothesis that the major occupation of Tuft Springs #1 was Late Archaic/Early Woodland with light occupation extending back through time to the Early Archaic and continuing into the Mississippian.

Tuft Springs #2 has a much higher percentage of fiber-tempered ceramics than does Tuft Springs #1 and the relative quantity of undecorated fiber-tempered ceramics is lower, suggesting a more intense occupation beginning slightly later than at Tuft Springs #1. The later ceramics, Swift Creek and Lamar, are much rarer than at Tuft Springs #1, indicating very sparse Woodland and almost no Mississippian occupations. The lithic remains suggest an earlier Archaic occupation; however, the evidence is too sketchy to be reliable. It is suggested, therefore, that Tuft Springs #2 has a very light Early Archaic, Woodland, and Mississippian occupation and that the peak period of occupation was during the latter portion of the Late Archaic.

The quantity of all types of material, the large quantity of lithics, the probable flooding, the lack of structures, and the site sizes for Tuft Springs #1 and #2 strongly suggest that these sites were occupied intermittently. The large quantity of bone found at Tuft Springs #1 compared to the later Stubbs Mound site (Williams 1975:125), the differential use of portions of the deer carcass, and the fracturing of bones to extract marrow indicate that hunting was carried out and that the animals killed were partially dismembered before returning to the site. Large quantities of mollusc shells indicate the collection of shellfish played an important role in the aboriginal economy. Note should also be made of the fact that at Tuft Springs #1 the ceramics are evenly distributed over the site, the lithics are found toward the outer edges of the site, and the bones cluster toward the center of the mound, suggesting differential site usage.

The above facts combined with those discussed previously suggest the following conclusions about the Late Archaic/Early Woodland occupation of Tuft Springs #1 and #2:

1) Each of these sites was occupied intermittently, probably as seasonal camps designed to exploit the resources of the swampy hardwood forest of the floodplain.

2) The primary function of these sites was as hunting camps, although a limited amount of vegetal matter was collected as were freshwater molluscs.

3) The resident population at each site probably was on the order of 20-25 individuals with the greater depth of deposit at Tuft Springs #1 and the larger amount of material suggesting a longer overall period of use or more frequent use or a slightly larger population or a combination of these.

4) It is a normal assumption that ceramics are associated with a sedentary way of life, but it is known that ceramics are carried on hunting trips. Therefore, we suggest that the individuals occupying these two sites were probably members of at least semi-sedentary groups and may indeed have been members of larger, more permanent villages during the period of major occupation.

5) The differential artifact distribution at Tuft Springs #1 indicates use of the entire site for ceramic-related activities but that lithic manufacture probably was carried out on the margins and most other daily tasks, including butchering, were carried out in the center of the site.

This reconstruction would apply to both earlier and later periods at these sites with the following changes. First, earlier occupation probably was by more freely wandering small bands. Second, later occupation was probably seasonal hunters from permanent agriculture based villages such as at Ocmulgee.

We thus have a picture of two temporary hunting camps occupied primarily at the Late Archaic/Early Woodland transition with use continuing after the appearance of agriculture and sedentary life.

Future investigation is needed to confirm this reconstruction. It is suggested that a small site located on the floodplain and exhibiting surface indications of occupation contemporary to Tuft Springs #1 and #2 should be excavated. Particular attention should be given to (1) the fiber-tempered ceramic sequence, (2) pollen analysis in order to reconstruct the contemporary flora, (3) detailed analysis of the lithic and faunal remains stressing as complete recovery as is possible, and (4) carefully controlled excavations to more firmly control the natural stratigraphy and locate features in order to establish the length of occupation, whether or not it was seasonal, and the presence or absence of structures.

LITERATURE CITED

RENDER, E. V. 1970. Forest Types Near Macon in 1827. Manuscript on file in the N.P.S. Southeast Archeological Center library.

DE, J. L. 1964. The Formative Cultures of the Carolina Piedmont. Trans. of the Am. Phil. Soc. vol. 54, part 5.

EWIS, T. M. N. and M. K. LEWIS. 1961. Eva: An Archaic Site.

ELSON, B. A., D. SWINDELL, and M. WILLIAMS. 1974. Analysis of Ocmulgee Bottoms Materials at the Southeast Archeological Center. Manuscript on file in the N.P.S. Southeast Archeological Center library.

STOUTAMIRE, J. W., C. O. BRALEY, T. R. GEST, and P. A. LOGAN. 1976. The Tuft Springs #1 (13Bi25) and #2 (13Bi19) Sites in Central Georgia Prehistory. Manuscript on file in the N.P.S. Southeast Archeological Center library.

WILLEY, G. R. n.d. Field Notes from Tuft Springs #1 and #2. Notebook 108 at the N.P.S. Southeast Archeological Center.

WILLIAMS, J. M. 1975. Stubbs Mound in Central Georgia Prehistory. Manuscript on file in the N.P.S. Southeast Archeological Center library.

HOMAGE TO GUSTAVUS CHENEY DOANE: SCIENCE IN OUR NATIONAL PARKS

Gary A. Wright[1]

In a recent article in *Natural History*, Joseph L. Sax (1976) examined, among other things, the question of the motivations of those individuals responsible for the creation of our National Park system. What were their goals and how do they relate to our present day situation? Sax found that there was neither a well articulated public demand nor any particular interest in a "Park-idea" in Congress at the time Yosemite was set aside from Federal lands. Beyond some generally unspecific references to "recreation," he found no satisfactory answer.

My own archaeological research in the Jackson Hole Country has led me to peruse many of the early documents pertaining to northwestern Wyoming, the home of Yellowstone and Grand Teton National Parks. My original intention was simply to collect whatever data I could from the floral, faunal, and ethnographic observations made by early travelers through that region. In the course of this work, many of the same questions addressed by Sax had begun to occur to me. Most of my conclusions echo Sax's. However, my current field program is oriented toward specific research goals in Yellowstone and Grant Teton. Thus, my perspective is different. National Parks are necessary to me, not only for aesthetic or recreational values, but also for basic science. Let me then review, first, the history of Yellowstone briefly from this viewpoint.

One of the sets of papers I have been examining derives from the Washburn-Langford-Doane Expedition to the Upper Yellowstone Country in 1870. Since Doane figures importantly in this paper, I shall concentrate on him. Doane's press has always been bad (Bonney and Bonney 1970; Calkins 1973:89-107) and it seems to me with good reason. He participated, for example, as an army Lieutenant in several Indian massacres and was proud of it. He made a disastrous winter trip by boat down the Snake River through Jackson Hole in 1876. It resulted in no new information and nearly caused the deaths of the entire party. My friend Jim Calkins has summarized Doane as follows:

> There is a peak in Yellowstone Park named for Gustavus Cheney Doane. Another one in the Tetons is called Doane Peak. It is 11,354 feet tall. It rises in the northern part of the range, but, like its namesake, does not loom large on the horizon (Calkins 1973:107).

Yet, out of all of the things we can find in this man's life to make us dislike him, he generated one idea that cannot be ignored. In 1870, Doane led the military escort for the Washburn-Langford-Doane Expedition. Its objective was to explore the Upper Yellowstone country. According to a Park Service creation myth, it was the members of this party who first conceived that National Park idea one evening while sitting around their campfire. Several of the civilians present at that historic rap session, along with others such as F. V. Hayden, worked, lobbied, and cajoled the members of Congress for a Yellowstone National Park. They were successful and on March 1, 1872, the bill was signed into law by President Grant.

Among the participants of the 1870 Expedition were some who had a scientific background. What I find significant about the articles they contributed concerning the expedition is that they concentrated on extolling the scenic and touristic value rather than the scientific importance of such a park. Let me give two examples from N. P. Langford writing in *Scribner's Monthly* in 1871. At one point he comments that with the coming of the North Pacific Railroad Yellowstone would be both accessible and attractive to "thousands of tourists" (Langford 1871:128). Early on in the journey he noted that Tower Falls would make an admirable location for a resort (Langford 1871:9). Even Hayden, himself, eight years after Yellowstone Park was founded, spoke of turning northwestern Wyoming into "a region of retreat for pleasure-seekers from every part of the world" (Hayden 1880:200).

From this perspective we can also examine the Public Park Act itself. In reading about the speeches concerning the bill it seems obvious that the first hurdle was to convince Congress that the Upper Yellowstone country was not only unfit for agriculture but, further, it did not contain mineral wealth in commercial quantities. This obstacle cleared, the bill is directed toward the preservation of floral, faunal, natural curiosities, and sundry wonders of nature that might amuse and astonish the general public (cf. Sax 1976, for Public Parks before Yellowstone). This is not to impugn these goals but, like the popular writing cited earlier, no mention of the scientific potential of a National Park or a series of such parks is considered. Perhaps this was the only feasible strategy to assure passage of the bill, but, since scientists were among the major protagonists, the absence of any reference to, or provision for, scientific research is conspicuous.

Doane's report, submitted in 1871, is a masterful account of that journey. Along with other articles and newspaper accounts prepared by the members of the party, they collectively answered many of the questions concerning the *terra incognita* of northwestern Wyoming in the affirmative: "Yes, Virginia, there really are geysers in that country." These publications served, in short, to bring to the attention of the public the existence of an unparalleled natural resource within the territorial boundaries of the United States.

Yet, Doane went farther than this alone and it is here that his name becomes relevant to my discussion of scientific research in our National Parks and why, despite his many unpraiseworthy deeds, some small amount of homage is due to him. Doane's report on the 1870 Expedition contained not only extensive descriptive material but he was the first, to my knowledge, to promulgate through publication the concept that such a region as the Upper Yellowstone country would have great importance not only for tourism but for science as well. Toward the close of the report he wrote:

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> As a country for sight seers, it is without parallel. As a field for scientific research it promises great results in the branches of Geology, Mineralogy, Botany, Zoology, and Ornithology.
>
> It is probably the greatest laboratory that nature furnishes on the surface of the earth (Bonney and Bonney 1970:387).

Now, undoubtedly, most scientists, even then, did not need the goading of an army Lieutenant to prod them into the field. In an article published in 1912 Schmeckebier reviewed scientific research in the National Parks during the 40 years following the establishment of Yellowstone. He noted the geologists, including glaciologists, had led the way, but that many other types of research were being conducted. He even mentioned in passing that "in the Mesa Verde National Park the remains of the vanished race of cliff dwellers offer a prolific field to the ethnologist and anthropologist" (Schmeckebier 1912:531).

He did voice one major complaint however. The information garnered through these research projects had generally failed to filter down to the interested lay public. Monographs and papers deriving from the field investigations were either unavailable or were so technical or turgid in style that they were virtually incomprehensible to the nonspecialist--and I might add probably to some experts as well. Happily, he noted, the Department of Interior had already recognized this dilemma and USGS maps of some of the parks were being readied for sale and pamphlets with accompanying plates and illustrations were being issued. Clearly, however, there was then, and in some instances today, a poor articulation among the three concerned communities: the scientists, the public, and the individual park management.

At this point I think we can recognize two, frequently opposing, forces in motion. On the one hand there were the scientists with particular, often narrow, but well-defined research interest, whether it be geysers, fossils, forests, or lungworms in elk. There are basic questions they want to answer because they are curious people. Yet, out there somewhere, and far too often out there somewhere means in the middle of your field camp at the wrong time of day, there are tourists who appear out of nowhere. For they too are curious people and they also want to know. "Hey, Professor! What kind of rock is this?" "Say, Doc, what Indian tribe lived here on this site you're diggin'?"

We can see this subtle interplay between pure research, Park Service goals and public responsibility almost right from the beginning. In my own archaeological project in Grand Teton I have found myself tugged to and fro. For instance, Grand Teton was by no means a natural unit from the perspective of the Native Americans who lived there. Some of the most important sites for understanding the prehistory of Jackson Hole and northwestern Wyoming lie beyond the boundaries of the administrative unit. The money for our work derives from the Park Service and it is contract work for Grand Teton. My own research interests, however, are not so bounded; nor, I might add, are the curiosities of the park visitors. Thus, in order to incorporate sites outside of the park into our research design, we must work overtime--on holidays as it were.

There is a second inherent difficulty from my own experience. The local park requires certain types of information from archaeology. Under the terms of our contracts we are duty bound to supply those data. The research design we would apply elsewhere may be totally inappropriate. If for example, the local park wishes a total inventory of archaeological sites we must survey the entire land surface. This necessitates a considerable expenditure of time. If, rather, a stratified sampling procedure based on topographi and ecological data input could have been employe countless wasted (from my research interest point of view) hours could have been avoided. For example, within the first week of the first season, it was clear that from an archaeological standpoint there was little reason to surface survey the glacial moraines of Grand Teton; I could predict there would be no sites on these prominent geological features. Still, from the vantagepoint of park management, if they desire to construct a Visitors' Center on Burned Ridge moraine they need to know that they will not destroy some portion of the park's heritage. Responsibility to the park must take precedence.

These are obvious points and I am sure that many of my colleagues who also have conducted research in our parks have undergone many of the same types of experiences. They can elaborate upon these themes in greater detail. I would prefer to spend my remaining time dealing with two issues that are perhaps less obvious, but of no less importance to the Park Service, the public, and to the scientist, in particular the archaeologist. In short, beyond the inventory of cultural resources and grist for interpretive programs, how might archaeological data assist in the formulation of management policies and how might the parks serve in basic research?

Citing a volume entitled *Administrative Policies for Natural Areas of the National Park System* (1968:17), Douglas Houston (1971:487) states that "the primary purpose of the National Park Service in administering natural areas is to maintain an area's ecosystem in as nearly a pristine condition as possible." Public education through interpretation by the naturalist programs employs the ecosystem concept as the basic underlying principle for conveying both knowledge to park visitors and for communicating Park Service management philosophy to the outside world. Contemporary studies conducted within the parks on flora, fauna, geomorphology, and so on are used for presenting to the tourists present day park ecosystems. It is from these fields of inquiry that we learn about population fluctuations of various species, land use, range conditions, migratory habits, species interrelationships, and a host of additional topics that are required in order to understand the modern ecosystem in question.

However, let me ask the following: what is a pristine ecosystem? Houston (1971) refers to "modern man" and his effects on the ecosystem. From the context of his paper I assume that modern man is the bearer of a sophisticated industrial technology of western European origin who first appeared in northwestern Wyoming in large numbers in the late nineteenth century. Leaving aside the fur trappers of a half a century earlier, who also modified the environment, I must point out that our archaeological data indicate that Native Americans were exploiting the Jackson Hole-Yellowstone area at least 10,000 years prior to white contact. I must argue that human groups at any cultural level through their interactions with the environment will have an affect on, and must be considered an integral feature of, any ecosystem of which they are a part. While it is certainly correct to argue that the effects are greater today, the term pristine is not well chosen because it is a static rather than a dynamic concept.

As an archaeologist I propose that we too have a responsibility here. The relevance of archaeological research lies not in the immediate--the arrowhead, the butchered bison, or the emperor's tomb--but in our examination of the interrelationship of our genus and the environment throughout our evolutionary history. Ecosystems change in many ways; some of these alterations have been man caused but by all means not all of them date since the Industrial Revolution.

Our archaeological research is important in two ways. First, it provides descriptions of environmental changes in the particular area under study. We normally employ such techniques as palynology in order to analyze vegetation changes. We utilize faunal studies, geomorphology, glaciology, and so on. These researches allow us, as well as nonarchaeologists, to understand environmental alterations before written records are available.

Secondly, and to my mind most importantly, is our focusing on this interaction between our genus and the environment. The prehistoric peoples of Jackson Hole were hunters and gatherers. They did not plow the soil for planting crops, nor did they strip mine. They were seasonal summer inhabitants of our valley and the mountains and while on the valley floor during the summer they relied most heavily on plant resources rather than large game animals. Neither agriculturalists nor pastoral herders, they were still consumers of natural products. How did they interact specifically? How did they modify? Let me give three examples.

Today, there is a protected herd of about 25 bison in Jackson Hole. There has been appreciable change in population size of this herd over the past two decades. This suggests that population stability has been attained for this ecosystem. Ethnohistoric documents from the 1820's and 1830's show that they were low in numbers then and frequently were absent from the valley altogether. Our data suggest that prehistorically bison were too undependable in numbers to serve as a predictable annual food source; thus they were never an important game species to the summer residents. Yet, they might be taken when locally available and we do have a natural trap site on the National Elk Refuge which has produced bison, mule deer, and black bear. There is one C-14 date of 390 radiocarbon years. The stratigraphy and projectile point styles indicate that the trap was used over a long period of time, perhaps a couple of millennia. From the perspective of bison-man interaction, we can see that with a low bison population, one successful kill of a number of adult animals would have reduced the breeding potential of the local herd to a level where it was no longer a significant part of the valley ecosystem. Only immigration from Yellowstone and/or the Green River Basin could have returned the population to a level at which killing could begin anew. This adverse affect on bison is a phenomenon that has been recorded elsewhere in the State of Wyoming by George Frison.

Secondly, our excavations have suggested that blue camas (*Camassia quamash*) was a highly desired resource in northern Jackson Hole. The distribution of archaeological sites may be predicted by knowing the location of camas meadows. We have roasting pits currently C-14 dated back to 1830 radiocarbon years, and some sites with these roasting pits have produced projectile points dating as early as ca. 8000 B.P. Blue camas is a major plant in the ecosystem of northern Grand Teton despite many millennia of harvesting by Native Americans. It has been suggested that a homeostatic mechanism operated between camas harvesting as a cultural practice and the continued existence of this species that might be termed agricultural in its broadest sense (see Reeve 1976). The disturbing of the soil and the breaking of the roots during the extraction process may have favored vegetative reproduction. If our present field experiments demonstrate this, the camas-man relationship can be seen as a self-regulatory one very much unlike the bison-man interaction described above.

The third example is fire. Soil cores and tree borings have proven that Jackson Hole has had a long history of fire, one that began well before the appearance of white trappers and settlers (see e.g., Loope and Gruell 1973). The role of fire in the ecosystem is now a major topic of research and its benefits are beginning to be appreciated. Taylor's (1973) study in Yellowstone has demonstrated that in the absence of fire, species diversity and the quantities of many species drop drastically after canopy closure, i.e., after about 25 years following the last fire. Some of the species so lost may be essential in the human ecosystem of hunters and gatherers.

Subareas within Jackson Hole in which impressive evidence of prehistoric occupation has been recorded by our surveys also generally exhibit fire remnant vegetation, as, for example, in the deep arroyos near Blacktail Butte in southern Grand Teton. We have found nearly three dozen sites near this prominent geographic landmark and have test excavated five of them. They cover at least 4000 years of occupation. There is one curious and quite interesting fact about these sites. Fire broken rock from campfires is abundant on these ancient living floors. But charcoal is virtually absent. Even though it takes but a scant four grams of charcoal for a radiocarbon date, not one site has yet produced enough for us to employ this technique. This is in direct contrast to our site at Two Ocean Lake from which we have three C-14 dates and charcoal enough from hearths for several additional ones.

As it is obvious that considerable cooking was done near Blacktail Butte, where, then, is the charcoal? Firepits here are shallow and this is a high wind area. I suggest that most of it was blown away, quite likely in many instances as still burning embers. The probability of accidental fires was undoubtedly high.

Here, periodic fires appear to have maintained a different constellation of plant species around our archaeological sites than what we find there today where sagebrush predominates. A fire at Blacktail Butte in 1872 resulted in major vegetation changes which were noted by Bradley (1873). Fire was an important tool--and I use this word intentionally--in the regulation of the human ecosystem, and ethnographic evidence clearly demonstrates that Native Americans understood this. Much of the argument over this point in the literature centers around whether or not Native Americans were intentionally setting such fires. It is clear that they did and it is equally clear that an accidental, but human-caused fire nonetheless, would do the job just as well.

Today's ecosystem in Grand Teton is not the same as the one in, say, A.D. 1500. There are two reasons then for this viewpoint. First, human groups will modify any environment of which they are a part; they will affect the distribution and population structure of the plants and animals which they are exploiting (e.g., for wild sheep see Wright and Miller 1976) and will likely cause secondary reactions on a host of additional

species. This interaction may be beneficial or deleterious in regard to individual species. Modern man has had a largely deleterious effect, but I repeat that whites were not the first to modify the environment of northwestern Wyoming.

Secondly, ecosystem studies require a sense of time, even beyond that of a few human generations of recorded history (here I am referring specifically to Jackson Hole). Archaeologists are trained to think precisely along those lines. A cursory glance at any of the data from pollen cores taken by us or those from Yellowstone Park should convince us that major vegetational changes have occurred in this area and some of these ecosystem changes have nothing to do with modern man or Native Americans. The earliest alterations seen in these cores followed the deglaciation of the region after the retreat of the Pinedale ice.

Let me further illustrate this point by considering an additional example from our own research. The first historic document describing Jackson Hole is the journal of Wilson Price Hunt, the leader of the Astorians who passed through here on their way West in 1811. Trappers' accounts continue sporadically until 1840. From then until 1880 written sources are rare but derive mainly from government surveys. Permanent settlement began in 1883.

For his monograph *The Shiras Moose in Jackson Hole, Wyoming,* Houston (1968) read many of these documents. He found that as late as 1880 there was no reported sightings of moose in Jackson Hole; in fact, they were specifically mentioned by hunters as being absent from the area. My examination of the same sources plus several additional ones leads me to agree fully with Houston: for the first 65 years during which we have documentary evidence there simply are no moose reported.

Houston suggested that one possible explanation might be that moose did occur in low numbers and that the population was maintained at this low level by Indian hunting. Our research indicates that this hypothesis is untenable. Today there are over 600 moose in Jackson Hole, but as I noted above only about 25 bison. Excavations have produced bison bone from three sites, but sites dating back in time some 8000 years have yet to yield a single moose bone. Many of these archaeological sites to which I am referring are located in prime moose habitat in northern Jackson Hole and on more than one occasion my crews have been forced to retreat from the field having been routed by a cow moose.

Further, our research suggests that by about A.D. 1600 the northward migration of Shoshonean speakers had begun to put pressure on the indigenous inhabitants of the Jackson Hole Country. This pressure was felt most strongly in their winter exploitative territories such as the upper Green River Basin and extreme eastern Idaho. This appears to have resulted in an abandonment of the Jackson Hole region by this date. Shortly after this event the horse appeared and Native Americans began an entirely new life style in the adjacent Plains, one which attracted not only the Shoshone but also other mountain peoples. Even if there had been hunting pressure on moose prior to this time interval, this abandonment meant that no hunting of any significance would have taken place between ca. A.D. 1600 and white contact (1810-1811). During these two centuries, moose, had they been present, should have expanded at least to the point where they would have received some mention in the documentary sources. Yet, it is not until the mid-1880's that the first moose are recorded. We must conclude that moose were in fact absent from the Grand Teton ecosystem until nearly the twentieth century and that Indian hunting had nothing to do with this absence.

Houston (1968) has proposed an additional hypothesis, one that intrigues me greatly in the context of this discussion. He suggests that it may have been the disturbance of the prewhite ecosystem by early settlers that permitted the migration of moose into Jackson Hole. This process would have been initiated by the digging of irrigation canals; these would have in turn increased the willow forage upon which the moose depend. Without this ecosystem alteration, then, this spendid animal would today quite probably be absent from Grand Teton, and it would be our loss

So far, my presentation has been one sided: what can we, as archaeologists, do for the Park Service? There is a reciprocity, however, for I work in Grand Teton and Yellowstone. They are my outdoor laboratory. Without these National Parks many of the theoretical questions in which I am interested could not be researched. Briefly, for example, one such problem has been the development of theoretical models for the understanding of the utilization of high country resources by nonagricultural peoples. Comparative investigations in southwestern Asia and Grand Teton have indicated that the scheduling of economic pursuits was structured around the periodicity characteristic of many high country species (Wright 1976). For instance, in Grand Teton we have recorded a dichotomous arrangement of base camps: on the valley floor at below 7000 feet and in the mountains at over 8000 feet. Many of the same plant species most important in the diet of these prehistoric hunters and gatherers, such as blue camas, tobacco root, bitteroot, etc., are found adjacent or near to both base camp locations. Significantly, the time of year that these species become available for exploitation is largely controlled by elevation; those plants of the same species found at higher elevations will be exploitable later in the growing season. In a high country adaptive system group movements were timed to take advantage of this phenomenon.

A second theoretical problem that has concerned us has been the question of Shoshone migrations, and some of our conclusions were presented above. Migration is a major theoretical problem within the wider context of Anthropology, but it was also relevant to the study of game populations in Jackson Hole just prior to the historic era. Thus, it seems clear that we can see that the opportunity for pure research continues to exist within the bounds of the more tightly structured contract work.

My final comments are ones that I approach with a great deal of pessimism. In our land species that once roamed the valleys and the high country, that filled our skies and waters, are now gone forever. They are extinct. A host of other species and genera are on the endangered list. If bald eagles still soar in Jackson Hole, they no longer do so over much of their former range. Their habitat has been destroyed. So is it too with archaeological sites. Site destruction is rampant in our land and fast increasing. I do not believe that Progress Is Our Most Important Product because in the end it costs us so much.

But excavations, even our own, destroy the very sites upon which we as archaeologists depend. The individual site is our most important laboratory for examining this man-environment interaction I have been discussing. As field archaeologists,

these sites are our major resource. They are the staff of our lives and it is in our National Parks that one mechanism exists for their adequate protection. Yet, sadly, in the past two years three sites were destroyed in Grand Teton because of a failure to coordinate archaeological input with the planning of construction activities. Still, we must and do excavate, and the burden is on us as well to see that this work is done properly. Our responsibility transcends not only the Park Service and the public but also our own discipline and our own future as field archaeologists.

Our parks, thus, beyond their scenic value are also storehouses of knowledge about the world in which we live. Lieutenant Doane called the Upper Yellowstone Country, "the greatest laboratory that nature furnishes on the surface of the earth." It behooves us who love that country and who work there to see that it always remains so. For we must remember that someday our National Parks may be the only natural laboratories on the surface of the earth, the single last vestige of the wild in our land, where we may follow our curiosities to wherever they may lead us.

I wish to thank the staff of Grand Teton National Park, in particular Charles McCurdy, Chief Naturalist, for their continual assistance over the past five field seasons; my field crews who have done all of the hard work; and Dr. F. A. Calabrese of the Midwest Archaeological Center who has seen to it that we have had financial and moral support.

LITERATURE CITED

BONNEY, O. H. and L. BONNEY. 1970. Battle Drums and Geysers: The Life and Journals of Lt. Gustavus Cheney Doane. Chicago: Swallow Press.

BRADLEY, F. H. 1873. Report of Frank H. Bradley, Geologist. U. S. Geological Survey of the Territories. Washington: U. S. Government Printing Office.

CALKINS, F. J. 1973. Jackson Hole. New York: Knopf.

HAYDEN, F. V. 1880. The Great West: Its Attractions and Resources. Philadelphia: Franklin Publishing Co.

HOUSTON, D. B. 1971. Ecosystems of National Parks. Science, 172:648-51.

_____. 1968. The Shiras Moose in Jackson Hole, Wyoming. Technical Bulletin No. 1, Grand Teton Natural History Association.

LANGFORD, N. P. 1871. The Wonders of the Yellowstone. Scribner's Monthly, 2:1-17, 113-128.

LOOPE, L. L. and G. E. GRUELL. 1973. The Ecological Role of Fire in the Jackson Hole Area, Northwestern Wyoming. Quaternary Research, 3:425-43.

REEVE, S. A. 1976. Prehistoric Transhumance in Jackson, Wyoming. Unpublished manuscript, on file Midwest Archaeological Center, Lincoln.

SAX, J. L. 1976. America's National Parks: Their Principles, Purposes, and Prospects. Natural History, 85(8):57-88.

SCHMECKEBIER, L. F. 1912. The National Parks from the Scientific and Educational Side. The Popular Science Monthly, 80:530-47.

TAYLOR, D. L. 1973. Some Ecological Implications of Forest Fire Control in Yellowstone National Park, Wyoming. Ecology, 54:1394-1396.

WRIGHT, G. A. 1976. High Country Adaptations: A Comparative Perspective. Paper presented at the 34th annual Plains Conference, Minneapolis.

WRIGHT, G. A. and S. J. MILLER. Prehistoric Hunting of New World Wild Sheep: Implications for the Study of Sheep Domestication. *In:* Cultural Change and Continuity: Essays in Honor of James B. Griffin, ed. C. E. Cleland, pp. 293-318. New York: Academic Press.

HOW OLD IS CAPULIN MOUNTAIN?: CORRELATION BETWEEN CAPULIN MOUNTAIN VOLCANIC FLOWS AND THE FOLSOM TYPE SITE, NORTHEASTERN NEW MEXICO

Adrienne B. Anderson and C. Vance Haynes, Jr.[1]

BACKGROUND

Capulin Mountain National Monument in northeastern New Mexico was established in 1916 to protect one of the more perfect cinder cones in the United States. Dating the volcano's eruption is valuable for interpretation and is of interest to the general public. After a study of the interfingering between basalt from Capulin Mountain and alluvial deposits that were dated as a result of work at the nearby Folsom Site, it was suggested that the cinder cone erupted between 10,000 and 4,500 years ago and that it may have affected paleo-Indian utilization of the area (Baldwin and Muehlberger 1959:111-112, 128-129, 156; Muehlberger 1955). Our recent work in the region indicates, however, that the alluvial picture is far more complicated than initially reported. Capulin Mountain's initial eruption is probably much earlier than previously believed and did not affect Folsom-age bison hunters.

Folsom Type Site

The importance of the Folsom Site is well known to New World prehistorians (Wormington 1957:23-29). It was here in 1926 that paleontologists excavating fossil bison remains discovered and recognized the significance of projectile points in direct association with the extinct species. This unprecedented discovery provided the irrefutable evidence that Early Man had hunted extinct Pleistocene megafauna in America and that he must be of late Pleistocene age himself. This discovery at Folsom came at a critical period in the development of archeological thought and it revolutionized the concept of man's antiquity in the New World (Bryan 1937b:139-140).

Area Location, General Physiography and Modern Environment

Capulin Mountain National Monument is 40 kilometers east of Raton, New Mexico. The Folsom Site is on the headwaters of the Dry Cimarron River less than 14 kilometers northwest of the cinder cone (Figures 1, 2). High, basalt-capped mesas, remnants of much more extensive volcanic flows that once covered the entire region (Levings 1951:10), extend along the Colorado-New Mexico border from Trinidad, Colorado east into Oklahoma (Figure 3). These flows, cinder cones and other vents scattered throughout the area represent several major periods of volcanic activity; Capulin Mountain dates from the most recent period of eruption.

The Johnson Mesa region, where the Folsom Site is located (Figure 3), is in transitional zone between the Short-grass Grassland of the Plains and the Ponderosa Pine (*Pinus ponderosa*) Forest of the Rocky Mountain Front Range. It falls within the broadly defined vegetational groups that Shelford (1963:295-305) calls Ecotone Woodland and Brushland Communities; specifically, the Oak Bushland region typified by Rocky Mountain Oak (*Quercus undulata*) and Mountain Mahogany (*Cercocarpus montanus*). The valley floor and mesa top are grasslands (*Bouteloua* spp., *Andropogon* spp.); the rim of the mesa is bordered in many places by large stands of Ponderosa Pine. The major stream banks support classic riparian vegetation (*Populus angustifolia, Salix* spp. *Typha angustifolia,* Cyperaceae). Dense thickets of scrub oak (*Q. undulata, Q. gambelii*), Mountain Mahogany and Pinyon Pine (*P. edulis*) dominate the hillslopes, and isolated fir (*Abis concolor*) and spruce (*Picea pungens*) individuals dot the north faces.

VOLCANIC HISTORY

The Raton-Clayton Volcanic Field has experienced three major periods of vulcanism since late Pliocene times: the Raton, the Clayton and the Capulin Mountain eruptions (Baldwin and Muehlberger 1959:152-157; Stobbe 1959; Stormer 1972a). Paleomagnetic dating of these basalts yielded unreliable results (Baldwin and Muehlberger 1959:112, 143-145), but potassium-argon dating by Stormer (1972b) suggested that the initial eruptions may have occurred as early as seven million years ago.

Raton Eruptions

The basalt capping Johnson Mesa represents the oldest period of vulcanism (Figure 4) and directly overlies the Ogallala High Plains surface (Baldwin and Muehlberger 1959:114). Johnson Mesa is the major remnant of the extensive Raton flows, which once covered the area.

Clayton Eruptions

After dissection of the high Raton surface had progressed to a point where the ancestral upper Dry Cimarron Valley was well-developed, a second period of volcanic activity began. These Clayton-period eruptions produced volcanos such as Jose Butte and associated flows that filled in the ancestral valley (Figure 2). Because of basalt scoria found in terrace deposits in Kansas, this period of eruption has been tentatively correlated with the Illinoian glaciation (Baldwin and Muehlberger 1959:154-156). After this volcanic activity ceased, dissection resumed until the valley was again dammed by basalt as the most recent period of eruption began.

Capulin Eruptions

One of the earliest events of the Capulin-period vulcanism was the eruption of Capulin Mountain itself. At this time a tongue of basalt from the cinder cone flowed northward into the Dry Cimarron River, covering a late Quaternary alluvial deposit (Figure 4). Subsequent eruptions of Capulin Mountain and other Capulin-age vents occurred throughout the area. Eventually, the Dry Cimarron River breached its lava dam which initiated the sequence of erosion and deposition that continues to the present day.

HISTORY OF THE FOLSOM SITE

The modern valley floor was undissected until extensive gullying began early in the 20th Century. Historic evidence (Anderson 1975:42-44) suggests that these arroyos started cutting after a disastrous flood in 1908. The flood began as a gentle, August rain in the headwaters of the upper Dry

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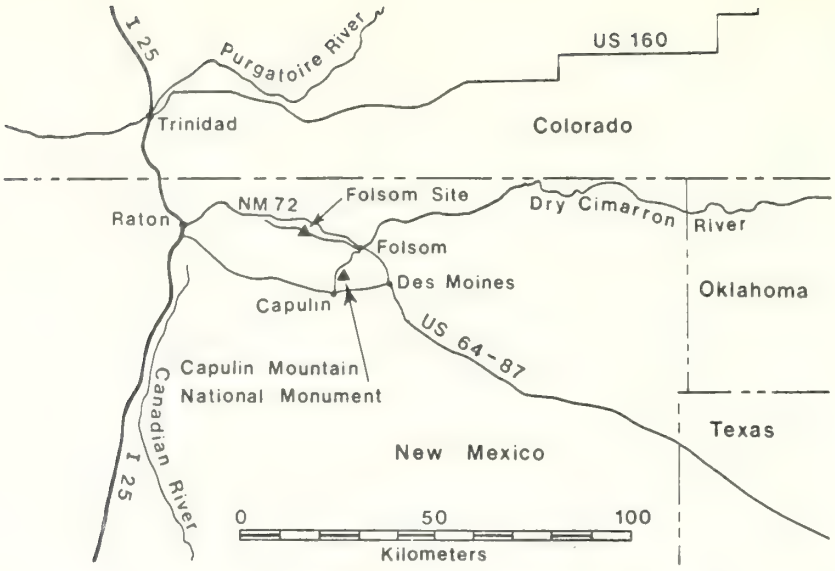

FIGURE 1. Locational map, northeastern New Mexico.

FIGURE 2. View southeeat from Johnson Mesa across the upper Dry Cimarron River Valley to distant volcanos (l to r) Sierra Grande, Capulin Mountain, Jose Butte and Mt. Robinson.

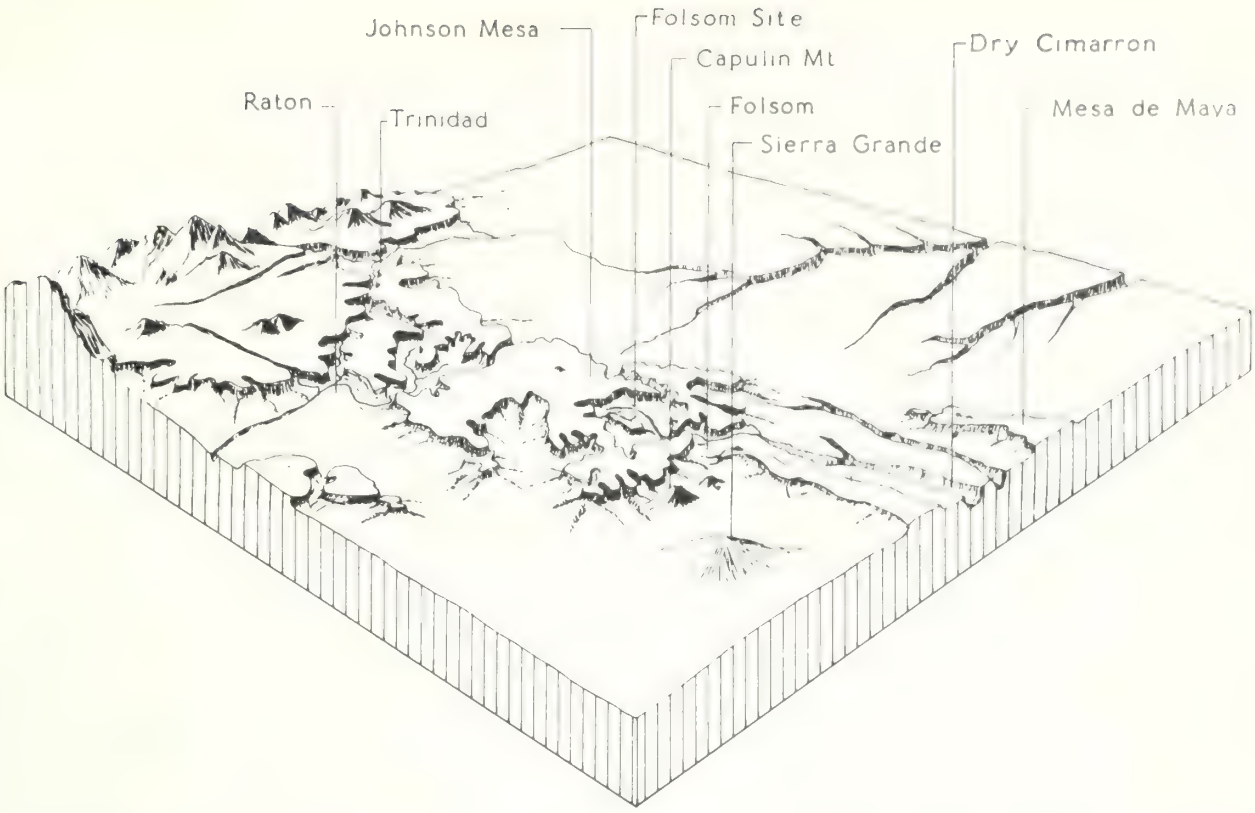

FIGURE 3. Raton-Clayton Volcanic Field, northeastern New Mexico and southeastern Colorado. View northwest.

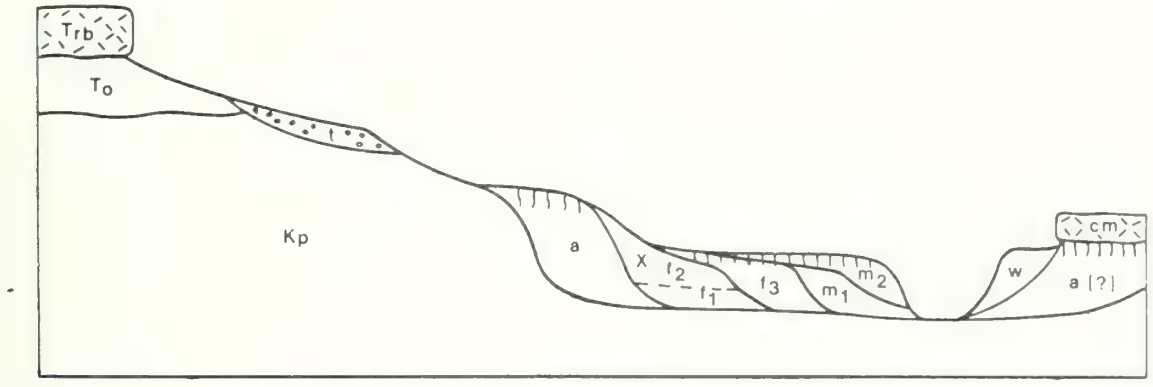

FIGURE 4. Generalized cross-section of the upper Dry Cimarron River Valley showing stratigraphic relationships: late Quaternary alluvial deposits (a,f,m,w), Capulin Mountain basalt (cm), terrace gravels (t), Raton-age basalt (Trb), Ogallala Formation (To), Pierre Shale (Kp) and Folsom occupation level (x). No scale.

Cimarron River, became a torrential downpour and by nightfall had almost completely destroyed the town of Folsom 13 kilometers downstream.

Sometime after this flood George McJunkin, a Crowfoot Ranch cowboy searching for stray cattle, guided his horse along Wild Horse Arroyo to a natural crossing. Here, about a meter and a half below the top of the bank, he discovered some huge bones protruding out of the arroyo wall. There is absolutely no evidence, however, that he located any cultural material. McJunkin, unfortunately, had no idea what he had found.

In 1925, several years after the cowboy's death, some of his friends undertook an expedition to discover for themselves what McJunkin had been talking about. After seeing the remains in place, one of the gentlemen realized that the find might be of paleontological significance. As a result, the bones were taken to the Colorado Museum of Natural History in Denver. One look at the materials was enough to excite Harold Cook, Honorary Curator of Paleontology, and early in the spring of 1926 Cook and Director Jessie D. Figgins visited the site.

In the wall of Wild Horse Arroyo they found sufficient evidence to suggest that excavation might be very profitable. According to Harold Cook's notes (1947), work was begun for three reasons: First, it was almost certain that the Museum would recover a new species of bison that could be described and exhibited. Secondly, and very important, the alluvial stratigraphy both at the site and throughout the valley made it possi-

ble to date the materials. The third reason for initiating excavation was the slight hope, fostered by charcoal in the matrix, that evidence of man might turn up.

Soon after work began the new species of bison appeared. The remains, studied by Colorado Museum personnel (Hay and Cook 1928, 1930), were designated *Bison taylori* [redesignated *B. antiquus* by Skinner and Kaisen (1947)]. Shortly thereafter the field foreman, Frank Figgins, was able to write the Director of the Museum, "Dad . . ., found the much sought for arrowhead this morning. It was in the matrix just inside of the spinal column of the animal" (Figgins 1926). The point, unfortunately, had not been found in-place.

Excavations continued the next year and at last a point was found undisturbed. Work ceased immediately and interested individuals were invited to view the remains for themselves. Some responded: anthropologists Frank Roberts, Fay Cooper Cole, Earl Morris, Clark Wissler, Ted Kidder and paleontologist Barnum Brown. Shortly thereafter Kidder wrote to Morris, "Went over to Raton at [Frank] Robert's request and looked at bison and points--damned interesting! Association is certain--question now is, is the deposit Pleistocene?" (Kidder 1927).

In 1928 large scale excavations proceeded under joint direction of the American Museum and the Colorado Museum. Kirk Bryan of Harvard University was requested to study the late Quaternary alluvium and thereby to date the remains (Brown 1929; Bryan 1937a, 1937b).

Geology and Dating

Bryan, using carbonate development and degree of weathering, divided deposits exposed in the deep arroyos into an "older" alluvium and a "younger" alluvium, thus representing two epicycles of cutting and filling. Bryan believed that the younger alluvium was post-Altithermal in age; the older contained the Folsom materials and *B. antiquus*. He clearly indicated, however, that this interpretation could be an oversimplification and that more cycles were probably represented (Bryan 1937b:142-143).

Relation to Capulin Mountain

In the 1950's Brewster Baldwin and William Muehlberger carried out general geologic investigations in northeastern New Mexico and provided a major synthesis of the area's volcanic history (Baldwin and Muehlberger 1959:111-157). The Raton-age eruptions capping Johnson Mesa were dated as late Pliocene or early Pleistocene; the Clayton-age eruptions were tentatively assigned to Illinoian times. Eruption of Capulin Mountain was placed between Bryan's older and younger alluvial depositions because of the aforementioned exposure where basalt from Capulin Mountain overlies what was considered to be the older alluvial material--the deposit containing the Folsom remains and *B. antiquus*. It was believed, therefore, that eruption of the cinder cone could not have predated approximately 10,000 years ago. This is the accepted period of Folsom occupation of the High Plains (Haynes 1967, 1968, 1971; Wormington 1957).

The more recent alluvium, which in places overlies the Capulin Mountain basalt, was also dated. In 1949 Harold Cook, one of the original investigators at the Folsom Site, submitted charcoal to Willard Libby that had been collected from a burned area within Bryan's younger alluvium (Cook 1949; Roberts 1951:20). The resultant solid carbon date of 4283 ± 250 (C-377) radiocarbon years substantiated Bryan's post-Altithermal age for the younger deposit (Arnold and Libby 1950:8; Johnson 1951:11; Libby 1955:107-108; Roberts 1951:20).

As a result of these dates on the two periods of deposition, eruption of Capulin Mountain was believed to have occurred between 10,000 and 4,500 years ago. Hence, it seemed possible that Folsom bison hunters witnessed the event.

REEVALUATION OF THE DATA

In the early 1970's Anderson (1975) reinvestigated the Pleistocene paleoecology of the Folsom Site and surrounding region; this provided the opportunity for Haynes (1970a) to reexamine the area's alluvial stratigraphy. It was readily apparent that the multiple epicycles of deposition and erosion suspected by Bryan (Brown 1929; Bryan 1937b:142-143) did exist (Haynes 1968, 1970a; Haynes and Anderson 1975, 1977). Moreover, materials were located during the project that provided good geochronological control. This has resulted in a much better understanding of the stratigraphic framework and the late Quaternary history of the upper Dry Cimmaron River valley.

Alluvial Chronology of the Upper Dry Cimarron River Valley

Close inspection of the alluvial exposures along the Dry Cimarron River and its tributaries (especially Wild Horse Arroyo where the Folsom Site is located) indicate that Bryan's older and younger alluviums could both be subdivided on the basis of lithology, buried soils and erosional contacts (Figure 4, Table 1).

ARCHULETTA FORMATION

The Archuletta formation has been observed only along Archuletta Creek, a major tributary to the Dry Cimarron River in the southern part of the valley. It forms a prominent 6-meter-high terrace composed of clay and gravel and yielded the only undisturbed remains of mammoth known in the region (Anderson 1975). Mammoths disappeared from the High Plains by 11,000 years ago (Haynes 1968, 1970b; Martin 1967:97). As far as can be determined, Bryan did not observe the Archuletta formation; it was not, therefore, part of his older alluvium.

FOLSOM FORMATION

The Folsom formation constitutes Bryan's older alluvium and is best exposed along the northern tributary drainages to the Dry Cimarron River. Backhoe trenches were dug at the Folsom Site in Wild Horse Arroyo to further explore the stratigraphy exposed in the deep arroyo walls. At the Site the lowest deposit (f_1) uncomformably overlies bedrock of Cretaceous Pierre Shale (Figure 4). Iron stains in the lower part of this silty clay suggest saturation by ground water after deposition; staining may have coincided with the deposit of f_3.

Unit f_2, a maximum of 1.8 meters of clayey silt containing numerous dispersed nodules of caliche ($CaCO_3$), conformably overlies f_1. The f_2 member contains the Folsom artifacts and skeletons of *B. antiquus*, partially encrusted with secondary calcium carbonate. The top of this unit has been eroded at all observed locations. Scattered lumps of charcoal occur sparingly in f_2, but the amount collected so far is insufficient for radiocarbon age determination. Although bone is notoriously subject to contamination, the bison remains from the Folsom level produced good collagen upon very

TABLE 1. Late Quaternary alluvial stratigraphy, Folsom Site vicinity, northeastern New Mexico.[a]

Unit	Description	Maximum thickness
	Wild Horse formation	
w	Sandy silt: dark gray (10YR4/1, 2/2 wet) interbedded light and dark gray layers (10-20 cm thick) of clayey sandy silt with thin layers of charcoal or decayed plants near top of unit and lenses of pebble to cobble gravel and shingle. Moderate medium prismatic soil structure at the top in some places. Late-prehistoric artifacts occur in the upper parts. Unconformably overlies m_2.	4.3m
	McJunkin formation	
m_2	Clay: very dark gray (10YR3/1, dry) to black (19YRw/1, moist) organic clay with rootlet molds and moderate, medium prismatic soil structure breaking to angular. Unconformably overlies m_1.	1.8m
m_1	Clayey silt: yellowish-brown (color not measured) clayey silt with alternating light and dark layers and thin layers of carbonized plants. Separated from m_2 by a weak erosional contact that truncates a black soil on m_1. Unconformably overlies f_3.	2.7m
	Folsom formation	
f_3	Silty clay: interbedded brown (10YR5/3, 3/3 wet) and dark grayish-brown (10YR4/2, 3/2 wet) silty clay with caliche nodules and strong, medium to coarse prismatic soil structure breaking to fine blocky. Dispersed charcoal in lower 25 centimeters. Unconformably overlies f_2	2.5m
f_2	Clayey silt: pale brown (10YR6/3, 4/3 moist) clayey silt with coarse caliche nodules, rootlet molds and iron stains. Interfingers with shingle colluvium adjacent to shale bedrock. Contains Folsom artifacts and scattered charcoal. Conformably overlies f_1.	1.8m
f_1	Silty clay: gray, iron stained clay (color not measured). Unconformably overlies bedrock Pierre Shale in observed exposures.	0.6m
	Archuletta formation	
a	Clay and gravel: light gray (2.5Y7/2, 5/2 wet) iron stained interbedded silty clay and pale yellow, clayey, silty gravel and shingle gravel. Mammoth bones found in upper meter. Base not exposed.	5.5m

[a]After Haynes and Anderson (1977).

careful pretreatment (Hassan 1976). The resulting date of 10,260 ± 110 B.P. (SMU-179) is in close agreement with dates from other Folsom sites (Haynes 1967, 1968, 1971).

The overlying unit (f_3) consists of irregularly laminated, calcareous silty clay and is eroded and buried in all known exposures. While it has a well-developed prismatic structure, there is no clearly discernable pedogenic zonation of the top. Instead, f_3 like f_2, evidences incipient soil development throughout in the form of calcareous root molds and carbonate coating on ped surfaces. This development suggests aggradation at a rate rapid enough to prevent clear differentiation of soil horizons. The laminated clays suggest a very shallow pond or a low-gradient discharge and shallow water table during deposition. This type of situation may have precipitated the iron staining in the lower portion of f_1. Carbonized plant remains or fine flecks of charcoal occur in the lower layers of f_3, but have not been collected in sufficient quantity for radiocarbon dating.

MCJUNKIN FORMATION

Bryan's younger alluvium, which unconformably overlies the Folsom formation, contains three units separated by erosional contacts. These are subdivided into the McJunkin and the Wild Horse formations (Table 1).

The lowest member (m_1) is a clayey silt up to 2.7 meters thick with lenses of charcoal and reddened earth apparently resulting from natural fires. Charcoal collected approximately a meter below the top of this unit provided a radiocarbon date of 6060 + 500 B.P. (Tx-1271). In some exposures red scoria pebbles occur in the upper part of m_1. A dark, clayey silty soil at the top of the unit is truncated by the erosional contact with m_2.

The upper member of the McJunkin formation (m_2) is characteristically grayer and darker than the lower units. In some exposures the upper meter is a black organic soil that obscures any erosional contact which may have been present. Charcoal from the upper member has yielded radiocarbon dates of 4850 + 120 B.P. (TX-1270) and 4470 ± 90 B.P. (Tx-1272); the early date of 4283 ± 250 B.P. submitted by Harold Cook also probably came from this unit.

WILD HORSE FORMATION

The youngest alluvial deposition is called the Wild Horse formation (w). It is a sandy silt with interbedded clayey, sandy silt and gravel lenses. In one exposure upstream from the Folsom Site, it consists of laminated clayey silt layers containing carbonized plant remains (*Vitis* sp.). In the Dry Cimarron River Valley Wild Horse alluvium forms a prominent 4-meter-high terrace in which late prehistoric artifacts have been found.

DISCUSSION

Folsom Occupation and Eruption of Capulin Mountain

After the subdivision of Bryan's older and

younger alluvial deposits and location of the earlier Archuletta formation, the exposure along the Dry Cimarron River where Capulin Mountain basalt overrode late Quaternary alluvium was re-evaluated. As the basalt flowed onto the moist, vegetated valley bottom it apparently baked an organic soil, samples of which were collected for dating purposes. The residue from carbonized plant remains yielded a date of 22,360 ± 1160 (Tx-1268) radiocarbon years ago. This date is either correct or is a minimum age because of possible contamination resulting from the fine-grained nature of the sample. Contamination in excess of 1% modern plant materials probably would have been detected in the laboratory during pre-treatment; it could not have produced an error exceeding two standard deviations. The humic acid, yielding a date of 13,860 ± 2170 B.P. (Tx-1269), apparently was contaminated by younger humic acid. This is not surprising considering the proximity of the sampled locality to the Dry Cimarron River and the ability of soil to absorb soluble humates (Haynes and Anderson 1977).

This exposure along the Dry Cimarron River led Muehlberger (1955) to believe the eruption of Capulin Mountain occurred between deposition of the older (the Folsom) and the younger (the McJunkin and Wild Horse) alluvial deposits. Our subdivision of these units suggests that the baked alluvium underlying the Capulin Mountain basalt is one of the fills predating the Folsom occupation. It could be equivalent in age to the Archuletta formation, as the radiocarbon dates suggest.

After the initial Capulin Mountain eruption, at least three other nearby volcanos erupted. The vesicular pyroclastic pebbles found in the lower part of the McJunkin formation (m_1) near the Folsom Site support Muehlberger's (1955) suggestion that this occurred after the Folsom occupation. It is not known, however, whether these pebbles fell on the alluvium during deposition or were redeposited there from older units. Evidence indicating redeposition has not been found.

SUMMARY

From the detailed stratigraphy now available we conclude that Capulin Mountain was dormant or extinct by the time Folsom hunters were on the scene and that the younger volcanos erupted later than paleo-Indian times. The bison kill near Folsom thus took place during a period of volcanic inactivity much as we are experiencing today. Folsom hunters did not observe the initial Capulin Mountain eruptions.

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LITERATURE CITED

ANDERSON, A. B. 1975. "Least cost" strategy and limited activity site location, upper Dry Cimarron River Valley, northeastern New Mexico Unpublished Ph.D. dissertation, Department of Anthropology, University of Colorado, Boulder

ARNOLD, J. R. and W. E. LIBBY. 1950. Radiocarbon dates. Southwestern Lore 17:6-8.

BALDWIN, B. and W. R. MUEHLBERGER. 1959. Geologic studies of Union County, New Mexico. State Bur. of Mines and Mineral Res., Bul. 63 New Mexico Institute of Mining and Technology Socorro.

BROWN, B. 1929. Folsom culture and its age. Geol. Soc. of Amer., Bul. 40:128-129.

BRYAN, K. 1937a. Geology of Folsom deposits in New Mexico and Colorado. Pan Amer. Geol. 67:373-374.

_____. 1937b. Geology of the Folsom deposits in New Mexico and Colorado: *In* Early Man, ed. G. Grant MacCurdy, pp. 139-152. J. P. Lippincott, Philadelphia.

COOK, H. J. 1947. Some background data on the original "Folsom Quarry" site and on those connected with its discovery and development. Mrs. Grayson Meade, Agate Springs Ranch, Harrison, Nebraska. ms.

_____. 1949. Letter transmitting charcoal sample to Dr. Willard F. Libby, Institute for Nuclear Studies, University of Chicago, December 7, 1949. Mrs. Grayson Meade, Agate Springs Ranch, Harrison, Nebraska.

FIGGINS, F. 1926. Field notes, Folsom bison quarry. Denver Museum of Natural History, Denver. ms.

HASSAN, A. 1976. Carbon isotopes: biological, environmental and experimental fractionation and their effect on radiocarbon dating of bone material. Ph.D. dissertation, Department of Geological Sciences, Southern Methodist University, Dallas.

HAY, O. P. and H. J. COOK. 1928. Preliminary descriptions of fossil mammals recently discovered in Oklahoma, Texas and New Mexico. Colo. Mus. of Nat. Hist., Proc. 8, No. 2.

_____. 1930. Fossil vertebrates collected near or in association with, human artifacts at localities near Colorado, Texas; Frederick, Oklahoma and Folsom, New Mexico. Colo. Mus. of Nat. Hist., Proc. 9, No. 2.

HAYNES, C. V., JR. 1967. Carbon-14 dates and early man in the new world: *In* Plei. Extinc., eds. P. S. Martin and H. E. Wright, Jr., pp. 267-286. Yale University Press, New Haven.

_____. 1968. Geochronology of late Quaternary alluvium: *In* Means of Corr. of Quat. Successions, eds. R. B. Morrison and H. E. Wright, Jr., pp. 591-631. University of Utah Press, Salt Lake City.

_____. 1970a. Field report on stratigraphic investigations of the Folsom Site. Universit of Colorado Museum, Boulder. ms.

_____. 1970b. Geochronology of man-mammoth sites and their bearings on the origin of the Llano complex: *In* Plei. and Recent Environ. of the Central Great Plains, eds. W. Dort, Jr and J. K. Jones, Jr., pp. 77-92. Department of Geology, University of Kansas, Special Publication 3.

_____. 1971. Time, environment and early man. Arctic Anthro. 8:3-14.

HAYNES, C. V. and A. ANDERSON. 1975. Geochronology of the Folsom Type Site. Paper presented at the 33rd Plains Conference, Lincoln, Nebraska.

_____. 1977. Geochronology of the Folsom Site. Quat. Res. in press.

JOHNSON, F. (assemb.) 1951. Radiocarbon dating. Soc. for Amer. Arch., Mem. 8.

KIDDER, A. V. 1927. September 11, 1927 letter to Earl Morris, Aztec, New Mexico from Alfred Vincent Kidder, Pecos, New Mexico. University of Colorado Museum, Boulder.

LEVINGS, W. S. 1951. Late Cenozoic erosional history of the Raton Mesa Region. Colo. School of Mines, Quat. 46, No. 3.

LIBBY, W. F. 1955. Radiocarbon dating, 2nd edition. University of Chicago Press, Chicago.

MARTIN, P. S. 1967. Prehistoric overkill: *In* Plei. Extinc., eds. P. S. Martin and H. E. Wright, Jr., pp. 75-120. Yale University Press, New Haven.

MUEHLBERGER, W. F. 1955. Relative age of Folsom man and Capulin Mountain eruption, Colfax and Union Counties, New Mexico (abstract). Geol. Soc. of Amer., Bul. 66:1600-1601.

ROBERTS, F. H. H., JR. 1951. Radiocarbon dates and early man: *In* Radiocarbon dating, assembled by F. Johnson, pp. 20-22. Soc. for Amer. Arch., Mem. 8.

SHELFORD, V. 1963. The Ecol. of N. Amer. University of Illinois Press, Urbana.

SKINNER, M. F. and O. C. KAISEN. 1947. The fossil bison of Alaska and preliminary revision of the genus. Amer. Mus. of Nat. Hist., Bul. 89, Art. 3.

STOBBE, H. R. 1949. Petrology of the volcanic rocks of northeastern New Mexico. Geol. Soc. of Amer., Bul. 60:1041-1095.

STORMER, J. C., JR. 1972a. The ages and nature of volcanic activity on the southern high plains, New Mexico and Colorado. Geol. Soc. of Amer., Bul. 83:2443-2448.

_____. 1972b. Minerology and petrology of the Raton-Clayton volcanic field, northeastern New Mexico. Geol. Soc. of Amer., Bull. 83:3299-3322.

WORMINGTON, H. M. 1957. Ancient man in North America. Denver Mus. of Nat. Hist., Pop. Ser. 4.

THE DEVELOPMENT OF A COMPLEX CULTURAL ECOSYSTEM IN THE CHACO BASIN, NEW MEXICO[1]

W. James Judge[2]

THE EXISTING DATA BASE

Cultural Summary

The archeology of Pueblo-III (Hosta Butte, Bonito, and McElmo Phases) in Chaco is fairly well-known (see Vivian and Mathews 1964 for a summary). Research since 1971 by the Chaco Center has helped clarify the earlier time periods. Recent archeological survey (Judge 1972 and Hayes 1975) has located some 2400 sites in the area. Although this is seemingly a large number, the Anasazi site density of 31 sites per square mile is less than half that found in the Mesa Verde area (81/m.^{2}). In terms of absolute population, Hayes has calculated that during the peak reached in the Bonito Phase, as many as 5600 people may have inhabited the canyon (1975:Fig. 26).

Early sites in Chaco Canyon are similar to contemporaneous sites elsewhere in the Southwest. Basketmaker-III sites tend to be quite typical, consisting of clusters of pithouses with an associated great kiva in some cases. Pithouses have antechambers and, frequently, external storage cists on the surface. The architectural transition to Pueblo-I, involving the shift to storage room/ramada areas behind the pithouses, dates in the 9th century A.D. (Windes 1976; Truell 1976). Absent in Chaco are the very large Pueblo-I villages found elsewhere in the Four Corners area (cf. Brew 1946).

Around A.D. 900, or perhaps earlier, the architectural and ceramic transition to Pueblo-II takes place, accompanied by an increase in site frequency and increased evidence of trade. From this time until the abandonment of the canyon in the 13th century, cultural change accelerates rapidly in Chaco. Full surface dwelling is achieved quickly, as is the transition from pithouse to kiva. Although direct tree-ring evidence is lacking, it is possible that the Hosta Butte Phase sites may have been started at this time or slightly later (e.g., the last half of the 10th century), resulting in full masonry kivas enclosed by a surrounding room block. Tree-ring clusters show evidence of initial construction at four of the "classic" Chacoan sites--Kin Bineola, Penasco Blanco, Pueblo Bonito, and Una Vida--between A.D. 900 and 950, and this evidence is generally confirmed by associated masonry styles.

By A.D. 1050, if not before, the transition to Pueblo-III was complete in Chaco. At Chetro Ketl, a classic Bonito Phase site, some 380 tree-ring dates have been collected, making it the most completely dated site in the area (Hawley 1934). Clusters of dates indicate that construction at Chetro Ketl started around A.D. 990 and it was expanded to roughly its present configuration during an extensive building period between A.D. 1038 and 1054. Although less well-dated, there is some evidence that Hungo Pavi also may have been constructed during the same period of time.

Another major building period, perhaps the most intensive in Chaco's prehistory, took place between 1055 and 1083. It was at this time that Pueblo Bonito acquired its present appearance. In addition, tree-ring clusters show contemporary building activities at Pueblo Pintado, Una Vida, and Penasco Blanco, as well as several other sites (Bannister 1964). In short, the 11th century in Chaco saw the construction of at least seven of the 13 classic Bonito Phase sites. These seven sites alone comprise an estimated 2,227 rooms, or an average of 318 rooms per site. Many southwestern sites contain as many rooms, however the size and construction techniques of Chacoan rooms makes them virtually unique. The quality of masonry is almost certainly superior to that found elsewhere in North America, and approaches or equals that encountered in Mexico and the Andes. In terms of size, "small" Chaco rooms average 16-18 square meters, while rooms in other southwestern sites average about 7 to 9 square meters. Chacoan builders used ponderosa beams generally, with some Douglas Fir, and evidence suggests that these might have been stockpiled and dried prior to use. Further, evidence from many of the sites reveals carefully planned, well-designed constructional units. Little, if any, growth by accretion took place during that period. Thus it is the rapidity with which construction took place, as well as the size and quality of the rooms built, that makes Chaco's Bonito Phase unique to Southwestern prehistory.

A final building period in Chaco took place early in the 12th century. By 1124, according to the tree-ring clusters, most of the classic sites had been completed, including the major Chacoan outliers. These "outliers" consist of sites physically separated from Chaco Canyon, yet exhibiting Chacoan masonry, Chacoan ceramics, great kivas or tower kivas, and connections to Chaco by means of a roadway and visual communication system (Drager 1976). They lie as close as 13 km., and as distant as 70 km., from Chaco Canyon. Recent research by the Chaco Center suggests that there may have been as many as 30 Chacoan outlying sites (Powers et al. 1977). Taken in conjunction with the 13 Bonito and McElmo Phase sites located in the canyon proper, a possible total of 43 major sites may have interacted during the A.D. 1000-1200 classic period. Hayes (1975) has estimated room counts on 24 of these sites, and arrived at a total of 3,956 rooms. Given this, and the assumption that a fixed ratio exists between room frequencies and population, it is easy to see why a relatively large increase in population has been suggested for the Pueblo-III period in the Chaco area (Hayes 1975:93).

The last tree-ring date from the Anasazi occupation of Chaco Canyon is A.D. 1178 from a firepit in the fill of a room at Kin Kletso. Hayes (1975) feels that there was a definite late occupation of the Canyon by Mesa Verde immigrants until the middle of the 13th century, but this did not rival in size the earlier Bonito/McElmo Phase population. Thus the classic occupation of Chaco Canyon was a very short-lived, yet intensive phenomenon.

Mentioned earlier was a roadway system connect-

[1]This paper is also recorded as Contribution No. 21 of the Chaco Center, National Park Service and University of New Mexico, for purposes of bibliographic control of research relating to Chaco Canyon.

[2]National Park Service, Chaco Center, Albuquerque, NM 87125.

ing the outlying Chacoan sites with those in the Canyon. Although Chacoan "roads" have been known for some time (Holsinger 1901; Judd 1954, 1964; Vivian 1972), defining the extent and location of the road network as a system has been the result of combined research by the Chaco Center and the Remote Sensing Center (Lyons & Hitchcock 1977). In the absence of wheeled vehicles and draft animals, the presence of wide (up to 9 meters) roads is difficult to explain. Yet there may have been as much as 200 miles of roads in the Chaco network during the Bonito Phase, connecting Chaco with its outliers, and connecting at least several of the outliers themselves. Some roads are masonry lined, others are merely troughs cleared in the sand, visible primarily on the horizon or on aerial imagery. They extend in generally straight lines with abrupt bends when necessary. An associated carved step/stairway system is present at cliff or shelf edges. It is virtually impossible to date the roads, although associated sites indicate heaviest use during the Bonito Phase. As paths rather than formal roads, however, these routes may have considerably more time depth.

Evidence of Trade in Chaco Canyon

Internal Trade

The term "internal trade" refers to those items that were brought into Chaco from areas within the Chaco region. Recent work on the analysis of ceramic temper types by Helene Warren at the Chaco Center has demonstrated that by far the majority of the pottery recovered archeologically in Chaco Canyon was not made there. Up to 80% of the Basketmaker wares were imported from the Cibola area to the southwest. During Pueblo-II times, up to 90% of the wares were imported, the decorated vessels from the Red Mesa Valley to the south, and the utility wares from the Chuska area to the west. At no time does the local manufacture of pottery exceed about 20%. In general, Warren (1976) concludes that utility and decorated wares were produced independently by different potters in different geographical locations, anywhere from 15 to 70 miles away. Her research is based on the analysis of temper types which come from deposits not known to exist in the Cliffhouse or Menafee formations outcropping in Chaco Canyon.

A similar situation exists for many of the lithic artifacts recovered from sites in the canyon. Materials known not to occur locally include varieties of chert, chalcedony, petrified wood, quartzite, and obsidian used in the production of chipped stone implements, as well as types of igneous rocks used for ground stone tools such as axes. In most cases, the source areas of these materials have been identified.

External Trade

External trade items are those which are known not to occur natively within the Chaco Region. These include turquoise and shell items, copper bells, and macaws. The frequency of turquoise artifacts recovered from Chaco is much higher than that from other southwestern sites. Literally hundreds of thousands of pieces were found in Pueblo Bonito, most in the form of beads. The abundance of turquoise found in Chaco, as well as the positive archeological evidence of bead manufacture there, strongly suggests its use as a medium of exchange during the Bonito Phase. Turquoise does not occur in the Chaco Basin. The nearest source known to have been mined prehistorically is that at Cerrillos, New Mexico, about 115 miles southeast of Chaco Canyon. The Cerrillos area is suspected as a primary source and trace elements studies are now underway to confirm this. Neutron activation analysis has shown that turquoise obtained from Chaco is mineralogically similar to some obtained from Mexico (Weigand, n.d.), indicating trade of the material between the two areas.

Over 1300 shell artifacts are known from Chaco. The majority of these (over 90%) are olivella shells which were strung as "necklaces." Bracelets made from glycymeris shells were also found, as were beads and pendants of several other species. Although these items are quite commonly found in other southwestern sites, they do indicate trade with coastal areas.

A total of 34 copper bells, cast by the lost wax method, have been recovered archeologically from Chaco Canyon. Since the working of copper was unknown to the prehistoric Southwest, these also provide direct evidence of trade with Mexico. A total of 23 scarlet macaws (*Ara macao*), 21 green macaws (*Ara militaris*), and 7 thick-billed parrots (*Rhynchopsitta pachyrhyncha*) have been found at Chaco, primarily from Pueblo Bonito where the evidence is that they were kept alive in cages (Pepper 1920:194-195; Judd 1954:264). With the exception of the parrot, these birds are native to areas south of southern Sonora, providing again direct evidence of trade with Mexico.

Environmental Data

Evidence from Chaco Canyon, derived from both recent and prior multidisciplinary research there, indicates that the climate during the Anasazi occupation did not differ much from that of today. Slightly drier conditions may have prevailed but even then the stream probably ran intermittently in an entrenched channel. General aggradation during the period was interrupted by several cycles of cutting which may have prevented valley floor flooding, although the water table fluctuated considerably. A positive filling episode was initiated around A.D. 1100, and continued until the old channel was buried. Modern cutting began in the mid-1800's. Soil studies suggest that soils derived from the headwaters of the Chaco are very highly alkaline and might have been generally unsuitable for farming (D. Love, pers. comm.).

Vegetatively, there was probably more pinyon cover than today, but there is little evidence for the presence of a ponderosa forest nearby (Hall 1975). Some Douglas Fir may have been present in north-facing rincons, fed by seeps or springs. When sparse local resources were depleted, ponderosa and Douglas Fir would have to have been brought in from sources as distant as 25-35 kilometers. A more complete, documented summary of the Chacoan paleoenvironment can be found in Judge (1977).

DERIVATION OF AN EXPLANATORY MODEL

Statement of the Problem

It is apparent that developments in Chaco from A.D. 900-1200 were probably unique to the prehistoric Southwest. Important questions raised by the "Chacoan phenomenon" are: 1) What kind of system of human interaction was taking place in Chaco? Was it basically religious, economic, socio-political, or some combination of these? Was a stratified society, virtually unknown in the egalitarian Southwest, involved? 2) How, and more importantly, why, did the phenomenon develop Was it the outgrowth of an evolutionary sequence indigenous to the Chaco Basin, or was it imposed upon indigens by peoples from elsewhere and if so from where? Why did development take place in

Chaco, generally devoid of natural resources? 3) What were the population parameters during the Bonito Phase? Did the population really double in the 11th century, as indicated by the room count, or was the area occupied on a less than permanent basis? 4) Finally, what caused the collapse of the system and the abandonment of Chaco Canyon, and how was this related to the physical, natural, and social environment?

These are the kinds of questions brought to mind by the events which took place in Chaco. If at this time a basic, general model can be derived which offers reasonable explanations for some or all of these questions, then refinement and testing can be approached later.

A Suggested Cultural Model

The following reconstruction is offered here as a trial formulation of events describing the Chacoan phenomenon. Based on ceramic evidence, movement of people and/or goods in the Chaco Basin was commonplace as early as Basketmaker/ Pueblo-1 times. Exchange was based on reciprocity among kinsmen in different areas of the Basin. Fundamental ties between outlying areas and Chaco Canyon were established, and reciprocal exchange served to help equalize differential access to resources as well as inequities in resource productivity (c.f. Bronitsky 1976; Schelberg 1976). Rainfall was not only sparse, but quite variable from place to place within the region.

By the first part of the 10th century, reciprocal exchange routes became more formalized, involving the movement of goods between sites and/or resource areas, instead of between kinsmen. The system at this time could be more appropriately termed an incipient redistributive network. Some storage of trade items probably took place in Chaco, which was centrally located within the region. Actual redistribution of goods may have taken place seasonally, as the majority of the perishable items became available. Craft specialization in the processing of turquoise began to develop at this time. The storage and exchange of goods could have been both stimulated and regulated by the use of turquoise, a highly valued commodity. Control over the production of turquoise, and thus the management of the redistributive system, was in the hands of the specialists.

During the 11th century, the redistributive network became highly formalized with Chaco Canyon as the economic, administrative, and possibly ceremonial center. Full-time administrative specialists as well as other craft specialists (e.g., turquoise processing, stone masonry) were being supported by the system. Control over the resource base was attained by Chaco in some, though perhaps not all, outlying areas in the form of satellite centers such as Kin Ya'a, Pueblo Pintado, and Aztec. Prior trade routes became highly formalized as a roadway system, supplemented by a complex visual communication network. Storage facilities in Chaco Canyon existed in the form of the large rooms in the Bonito Phase sites. Possibly, these sites were end points on roads into Chaco from various outlying areas, thus controlling resource acquisition from these areas. Formal redistributive events, during which people from outlying areas would aggregate in Chaco Canyon, were scheduled by the administrative specialists on a regular basis. Actual exchange within the Canyon probably took place at a central locus, such as Pueblo Bonito or Chetro Ketl, after goods had been stockpiled at the other canyon sites.

Except for scheduled aggregations during redistributive events, the population in the Canyon was not necessarily large. Small caretaker groups could have maintained the sites, and these in addition to the craft and administrative specialists would have accounted for the permanent population. The permanent population in Chaco would have been supported largely by the redistributive system as a whole and thus would have been relatively free of local environmental constraints.

It will be noted that this particular model assumes the Bonito Phase is an outgrowth of a sequence of events which took place *within* the Chaco Basin. Before considering the alternative, i.e., a system imposed on the Chacoan population from the outside by a presumably more advanced people, it seems reasonable to examine the implications of this model in more detail. If it cannot be supported, then alternatives should be considered. The remainder of this paper will deal with an examination of a possible ecological basis for the model.

A Suggested Ecological Basis for the Model

In searching for an explanatory basis for the processes outlined above, it is appropriate to view the Chaco Basin analytically as an ecosystem in which man, as a cultural species, was an integral part. The same basic ecological principles apply equally in this case as in other ecosystems, i.e., principles of energy distribution, diversity, trophic levels, succession, stability, etc. The only difference would be that change involving the human element would take place more rapidly since cultural, rather than genetic, adaptations would be involved.

Viewing this ecosystem during Basketmaker times, man is seen occupying a very generalized subsistence strategy, based primarily on horticulture and gathering. In a sense he was fundamentally a primary consumer, quite directly dependent on the environment for survival. Whereas other primary consumers (e.g., herbivores) depend on mobility to compensate for environmentally induced variations in net productivity, such compensations by sedentary humans would have taken the form of increased dependence on storage facilities and wild food sources, and reciprocal exchange with areas of higher productivity. This view of man's role fits very well Odum's definition of ecological niche as "the position or status of an organism within its community and ecosystem resulting from the organism's structural adaptations, physiological responses, and specific behavior (inherited or learned)" (1959).

The total energy available for human consumption would be a function of the net productivity of the ecosystem, and thus would be limited by the physical environment. In the Chaco Basin, productivity would be almost directly related to available moisture in the form of rainfall. The rather delicate balance of this system could have been disturbed by environmental deterioration during the 9th century. Further aggregation would have resulted from the possibility that the human ecological niche may have been saturated with individuals at that time.

Several responses to this situation could be anticipated, such as migration from the ecosystem, alteration of niche breadth, etc. However, another alternative could be that of adaptation to a higher trophic level, which is one method of increasing the efficiency of resource utilization (Pianka 1974:144). Community diversity is enhanced by such trophic differences, and some hold that stability is also increased (MacArthur 1955).

It is therefore suggested that niche diffentia-

tion took place within the human component of the ecosystem sometime early in the 10th century. The new trophic niche was occupied by only a small segment of the population--the full-time specialists--that had advanced to a level where subsistence was derived primarily from the energy produced by others. These specialists can be viewed analytically as secondary consumers in the sense of ecosystem energetics. They would have achieved an independence from environmental constraints not enjoyed by the primary consumers at a lower trophic level.

Such ecological advances could have taken place within the human component of an ecosystem only as certain preconditions were met. For instance, in an arid and unstable environment, it is unlikely that a single human community could support full-time specialists. Therefore an exchange network would have to have existed which would permit such support to be drawn from multiple sources within the ecosystem. Furthermore, during conditions of environmental deterioration, the alternative of migration from the ecosystem must have been unattractive, e.g., saturation conditions must have existed elsewhere as well. Finally, only a small portion of the population could make a trophic shift of this nature, due to the 89-90% energy reduction that occurs between trophic levels of a biotic community.

Given the satisfaction of the prerequisites, one might suggest that such a shift by a segment of the human component would, through efficiently managing the redistribution of resources, serve to increase niche breadth of the human component of the ecosystem as a whole. The net effect would be an increase in the stability of primary production, as well as a resultant increase in community stability. Such stability would be very valuable in a marginal environment such as that of the Chaco Basin. In Margalef's (1963) terms, the ecosystem would have matured, and succession would have taken place.

If the shift to a redistributive system supporting various specialists has a valid ecological basis, are there ecological reasons for the collapse of the system as well? It might be suggested that the new trophic niche would become quickly saturated with individuals, taxing the amount of energy the environment could provide. Given this degree of saturation, even limited environmental deterioration would result in a reduction of productivity and insufficient energy to support secondary consumers. Since the redistributive system could not function without specialists to maintain it, collapse would have come quickly. It is interesting to point out that while environmental deterioration at the center of the region could have initiated the shift to the formal redistributive system, is could have been environmental deterioration in the peripheral resource areas which brought about its demise.

Finally, one might ask what advantages are accrued by suggesting an ecological basis for the cultural model of redistribution in the Chaco Basin? As Pinaka has pointed out, the concept of niche can be defined as "the sum total of the adaptations of an organismic unit" (1974:190). As such, there is an intimate relationship between niche, adaptive radiation, and evolution, and the cultural model thereby acquires a much more powerful explanatory basis than it had before. This holds true for explaining the origin as well as the demise of the system modeled.

Further, the application of ecological principles of energetics and energy flow opens up a wide variety of analytic possibilities unavailable otherwise. For example, knowing the general reduction in energy available to successive trophic levels in an ecosystem, it might be possible to estimate the net annual production of the Chaco Basin and then estimate the maximum number of full-time specialists the system could support. Such an endeavor would give us a much different perspective on understanding the Chacoan phenomenon and assessing the validity of explanations for it. It is felt that these as well as other advantages provide a more adequate basis for pursuing the development, refinement and testing of this model in more detail.

CONCLUSIONS

I would like to summarize briefly by emphasizing several key points which are fundamental to the evolutionary model proposed above. First, it must be demonstrated that there existed positive selective advantages to the evolution of a system of redistributive exchange as postulated here. Second, it is assumed that the redistributive system requires the services of full-time specialists in order to operate effectively. Third, it was suggested that several preconditions be met in order for the system to become operational in an arid environment. And finally, it is recognized that the system has very definite environmental limitations, i.e., given the specific level of human technology represented, the longevity of the adaptation may be directly related to the stability of the environment. In a more stable environment, the system could, and in the case of temperate zones probably did, endure and continue to evolve.

Contrast this evolutionary model with the alternative, i.e., that the system was imposed on the inhabitants of the Chaco Basin by outsiders (Mexican Pochteca?). It would seem to me that some form of redistributive system similar to that postulated here would still be required to explain the Bonito Phase developments. The difference would lie in the nature of the stimulus needed to acquire it. Further, there would still be environmental limitations on the ecosystem as a whole, thus an ecological approach remains most appropriate for understanding the basic energetics of the system, including the number of specialists (Pochteca or otherwise) it could support.

The fundamental question for those interested in understanding processes of human behavior is in what way is the origin of the Chacoan phenomenon related to its demise? If imposed from the outside initially, then did the collapse occur because the parent system failed elsewhere, or on the other hand, is the environment of the Chaco Basin ultimately responsible for arresting the development, regardless of the nature of the origin? I admit it would be easier at this point to blame the Chaco failure on somebody else; the Toltec collapse, for instance. However, I feel we owe it to ourselves as scientists to define and investigate alternatives in the hope that a fuller understanding can be achieved.

LITERATURE CITED

BANNISTER, B. 1964. Tree-Ring Dating of the Archeological Sites in the Chaco Canyon Region, New Mexico. Southwestern Monuments Association, Technical Series, Vol. 6, Part 2, Globe.

BREW, J. O. 1946. Archaeology of Alkali Ridge, Southeastern Utah. Peabody Museum, Harvard University, Papers: Vol. XXI.

BRONITSKY, G. 1976. An Ecological Model of Trade. Ms., Department of Anthropology, University of Arizona, Tucson.

DRAGER, D. L. 1976. An Analysis of a Possible Communication System in the San Juan Basin of

New Mexico. Ms., Chaco Center, University of New Mexico.
HALL, S. A. 1975. Stratigraphy and Palynology of Quaternary Alluvium at Chaco Canyon, New Mexico. PhD. Dissertation, University of Michigan, Ann Arbor.
HAWLEY, F. M. 1934. The Significance of the Dated Prehistory of Chetro Ketl. Monographs of the School of American Research, No. 2.
HAYES, A. C. (n.d.) A Survey of Chaco Canyon Archeology. Contribution No. 13, Chaco Center, National Park Service. (In press)
HOLSINGER, S. J. 1901. Report on Prehistoric Ruins of Chaco Canyon National Monument. General Land Office Ms., National Archives, Washington, D. C.
JUDD, N. M. 1954. The Material Culture of Pueblo Bonito. Smithsonian Miscellaneous Collections, Vol. 124, Washington, D. C.
_____. 1964. The Architecture of Pueblo Bonito. Smithsonian Institution Miscellaneous Collections, Vol. 147, No. 1, Washington.
JUDGE, W. J. 1972. An Archeological Survey of the Chaco Canyon Area. N.P.S. Contract No. 14-10-7:931-51. Ms., Chaco Center, National Park Service.
_____. 1977. Research Design: The Excavation of Pueblo Alto. Ms., Chaco Center, National Park Service.
LYONS, T. R. and R. HITCHCOCK. 1977. Remote Sensing Interpretation of an Anasazi Land Route System. *In* T. R. Lyons and R. K. Hitchcock, Eds., Aerial Remote Sensing Techniques in Archeology. Reports of the Chaco Center, No. 2, National Park Service and University of New Mexico.
MACARTHUR, R. H. 1955. Fluctuations of Animal Populations, and a Measure of Community Stability. Ecology 36:533-536.
MARGALEF, R. 1963. On Certain Unifying Principles in Ecology. American Naturalist 47:357-374.
ODUM, EUGENE P. 1959. Fundamentals of Ecology, 2nd Edition, W. B. Saunders Company, Philadelphia.
PEPPER, G. H. 1920. Pueblo Bonito. American Museum of Natural History, Anthropological Papers, Vol. 27. New York.
PIANKA, E. R. 1974. Evolutionary Ecology. New York, Harper & Row.
POWERS, R., S. LEKSON and W. GILLESPIE. 1977. Preliminary investigations into the Chacoan Outlier System: A Functional and Regional Perspective. Ms., Chaco Center, National Park Service.
SCHELBERG, J. D. 1976. The Relationship of Trade and Environmental Stability. Ms., Department of Anthropology, Northwestern University.
TRUELL, M. L. 1976. The Architecture and Stratigraphy of Site 29SJ628. Ms., Chaco Center, National Park Service.
VIVIAN, G. and T. W. MATHEWS. 1964. Kin Kletso: A Pueblo III Community in Chaco Canyon, New Mexico. Southwestern Monuments Association, Technical Series, Vol. 6, Part 1, Globe.
VIVIAN, R. G. 1972. Prehistoric Water Conservation in Chaco Canyon. Final Technical Report, N.S.F. Grant No. GS-3100. Ms., Chaco Center.
WARREN, A. H. 1976. Technological Studies of the Pottery of Chaco Canyon. Ms., Chaco Center, National Park Service.
WEIGAND, P. C. et al. (n.d.) Turquoise Sources and Source Analysis: Mesoamerica and the Southwestern U.S.A. In, "Exchange Systems in Prehistory," J. Ericson and T. Earle, Eds., Academic Press, New York. (In press)
WINDES, T. C. 1976. The Architecture and Stratigraphy of Site 29SJ724. Ms., Chaco Center, National Park Service.

ARCHAEOLOGICAL RESEARCH IN NATIONAL PARK SERVICE AREAS: THE UNIVERSITY OF COLORADO EXAMPLE

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INTRODUCTION

Examples of University of Colorado archaeological projects conducted in conjunction with the National Park Service since 1963 are the primary topic of this discussion. The University of Colorado has a history of participation in archaeological research in National Park Service areas, both within and outside of the state of Colorado. The famous Earl H. Morris carried out extensive excavations and ruins restorations at Aztec National Monument in the 1920's. These were conducted in conjunction with the American Museum of Natural History (Morris 1919a, 1919b, 1921, 1924, 1928). Morris also conducted research excavations and ruin stabilization in Canyon de Chelley National Monument (Morris 1925, 1938, 1941, 1948, 1951).

The first archaeological investigations in Dinosaur National Monument were undertaken by Charles Scoggin in the 1940's. These were sponsored by the University of Colorado Museum. Scoggin was joined by Robert F. Burgh, who later assembled the results of that pioneering field research (Burgh and Scoggin 1948). The University of Colorado continued its interest in Dinosaur National Monument after World War II; first with work by Herbert W. Dick and later by Robert H. Lister (Lister 1951).

In the 1950's Lister excavated three pueblo ruins in the Far View Group at Mesa Verde National Park (Lister 1964, 1965, 1966) and Wilfred M. Husted, working under Lister's supervision, conducted an archaeological inventory for portions of the high altitude sections of Rocky Mountain National Park (Husted 1962, 1964).

Since 1963, two projects have been conducted for the National Park Service in other states, notably at Navajo National Monument (Breternitz 1969) and Pipestone National Monument (Sigstad 1968a, 1968b). However, I will confine further comments to federally funded projects conducted by the University of Colorado within the state of Colorado.

LEGAL BACKGROUND AND BASIS FOR FUNDING

The passage of several Congressional bills and Executive directives has stimulated and sanctioned much of the archaeological work done on land under federal jurisdiction or projects requiring federal licensing or federal funding. The most important of the recent legislation affecting Cultural Resource Management is:

(1) The Reservoir Salvage Act of 1960 (Public Law 86-523);

(2) Section 106 of the National Historic Preservation Act of 1966 (Public Law 89-665);

(3) The National Environmental Policy Act of 1969 (Public Law 91-190);

(4) Executive Order 11593, Protection and Enhancement of the Cultural Environment, 1971; and

(5) The Archaeological Conservation Act of 1974 (Public Law 93-291).

Other federal, state and local legislation has some effect on cultural resource activities, but the above mandates are the basis for most of the archaeological research currently being conducted in National Park Service areas or on other federal lands with funds administered by the National Park Service.

Within National Park Service areas funding is provided by the Service for specific projects, usually to satisfy the requirements of the above-cited legislation. Other funds, most frequently in the form of National Science Foundation Grants, are sometimes provided to conduct projects sponsored by university, museum or private agency research.

Until recently agencies such as the Bureau of Reclamation have utilized the expertise of the National Park Service to administer funds designated by those agencies to comply with their legal and moral requirements to investigate and protect cultural resources. These cooperative services are provided by designated National Park Service officials operating from the Midwest and other Archeological Centers, the three Interagency Archeological Services Division offices in Atlanta, Denver or San Francisco, and/or the Regional Offices.

TYPES OF PROJECTS UNDERTAKEN

For the time period and area under discussion the projects involving Cultural Resource Management can be classified into four categories:

(1) Cultural resource inventory.

(2) Test excavations.

(3) Research excavations.

(4) Salvage excavations.

Examples of each will be discussed. National Park Service and other federal project areas within Colorado where archaeological research has been conducted since 1963 are shown in Figure 1.

Cultural Resource Inventory

The recording of all prehistoric and historic cultural resources within an area for the purpose of creating an archaeological base map falls within this activity. Also, inventory for proposed construction, planning and development, whether by the National Park Service or other federal agencies, also falls within this category. Ideally, cultural resource inventory is *not* a procedure of sampling, but consists of the

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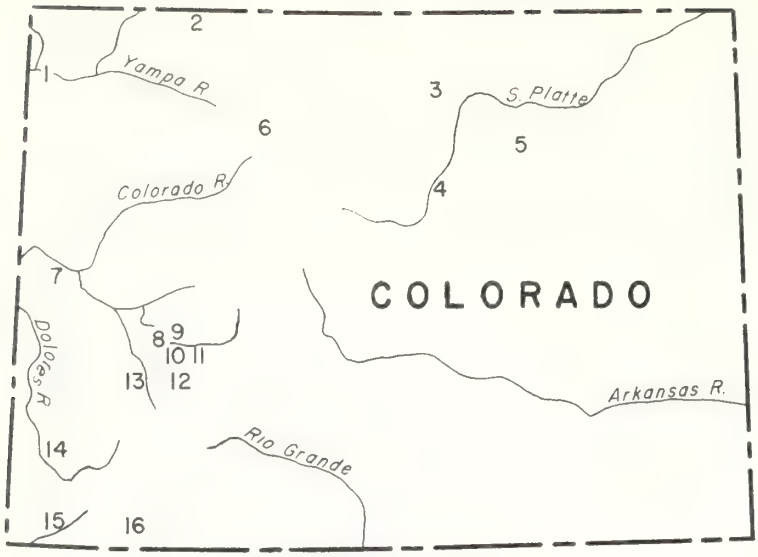

1. Dinosaur National Monument - I, RE
2. Savery-Pothook - I
3. Hayden-Ault Transmission Line - I, TE
4. Two Forks Project - I, TE
5. Bijou Basin Reservoirs - I, TE
6. Yam-Colo Reservoir - I
7. Colorado National Monument - I, TE
8. Black Canyon of the Gunnison National Monument - I
9. Fruitland Mesa Project - I
10. Crystal Dam - I
11. Curecanti Recreation Area - I
12. Silver Jack Reservoir - I
13. Dallas Creek Project - I
14. Dolores River Project - I
15. Mesa Verde National Park - I, RE, SE, TE
16. Animas-La Plata Project - I

I - Inventory
RE - Research Excavations
SE - Salvage Excavations
TE - Test Excavations

FIGURE 1. Areas in Colorado where the University of Colorado has conducted archaeological research for the National Park Service since 1963.

compilation of *all* cultural resource information for an area. This type of survey has been stimulated by Executive Order 11593.

Inventories are usually called surveys by most archaeologists. I consider an inventory to be as near to a 100 percent sample as possible. There are, however, various degrees of survey or inventory recognized by archaeologists and federal agencies. For background information denotation of these degrees or "types" of investigation is worthwhile.

Ruppe (1966) designates four "types" of archaeological surveys:

Type I. A catalog of sites, in this case primarily prehistoric, based on field reconnaissance of explorative activities.

Type II. A brief survey conducted in conjunction with a specific program of excavation.

Type III. A limited survey, problem-oriented, for some explicit reason.

Type IV. An intensive survey for a local area.

Certain government agencies have modified Ruppe's survey types to meet legal, monetary, and moral obligations, plus the vagaries of real life. For instance, the U.S. Forest Service designates surveys on four levels:

Level I. An overview consisting of a literature search of the area in question.

Level II. A reconnaissance survey which is more intensive than Level I and involving on-the-ground investigation.

Level III. A sample survey, either designated by the contracting agency or based on the results of the preceding Levels I and II surveys.

Level IV. An intensive survey which consists of a 100 percent coverage of the area.

I personally regard a Level IV survey to be, in effect, a cultural resource inventory.

Regardless of which terminology we choose to use, the majority of Cultural Resource Management projects done today begin with some sort of literature search or sampling survey. These procedures are important at all levels of research for evaluation, planning and protection of cultural resources. In addition, a vast amount of data have been accumulated during the past few years as a result of these activities. Some of these reports are not archaeological, but are historical, botanical, zoological, geological or studies in other fields of investigation which are important parts of the cultural resource inventories and subsequent programmed research, e.g., Birkedal (1976); Breternitz (1973); Cutler (1969); Cutler and Blake (1976); Malde (n.d.); Scott (1974); Wyckoff (1974, 1976).

Test Excavations

Completion of a field inventory/survey is followed by laboratory analysis and evaluation of the materials recovered or observed. From these data it may be determined that test excavations are needed to evaluate the extent, content and relative importance of subsurface cultural manifestations. Test excavations may be problem-oriented and/or designed to justify a "clearance" for construction, protection or development. Test excavations are, in effect, subsurface sampling procedures dictated by the scope of the particular project. Test excavations may eventually lead to either research or salvage excavations.

Research Excavations

To solve specific problems or to answer particular questions, research excavations might be conducted. If the potential for providing this information exists, problem-oriented research excavations are justified. It is this category of field investigation that will often require funding from sources such as the National Science Foundation or park Nature Associations.

Research excavations, in part sponsored by the National Science Foundation through research grants and support of undergraduate trainee programs in archaeology, have been conducted by the University of Colorado in Dinosaur National Monument and Mesa Verde National Park (Breternitz 1970, n.d.; Breternitz and Lister n.d.; Lister 1967; Smith n.d.).

Salvage Excavations

Destruction of cultural resources, primarily through programmed construction and development, constitute the fourth category of cultural resource investigation. These endeavors are exemplified by the published results of work in

Mesa Verde National Park (Lister 1968) and a series of additional reports submitted to the appropriate National Park Service office which have a more limited distribution. Funds for salvage are provided generally by the agency undertaking the project. Though they may be thought of administratively as "salvage" operations to obtain data that might otherwise be lost, in reality most salvage projects are now planned and executed as research projects designed to answer specific problems while "salvaging" the data.

SUMMARY

During the past fourteen years, the University of Colorado has undertaken archaeological investigations within National Park Service areas in Colorado, or in areas where contracts have been administered by the National Park Service, in sixteen different project areas. Some 44 separate contracts have been negotiated for this research. Categories of investigation include: cultural resource inventories, test, research, and salvage excavations, as well as a variety of ancillary studies.

The University of Colorado, as an example, typifies the range of cultural resource activities being conducted under National Park Service aegis, the purpose for which some of these projects are implemented, and the attendant scienfific, planning, and legally sanctioned results.

LITERATURE CITED

BIRKEDAL, T. G. 1976. Dating the sites (tree-ring and archaeomagnetic dating). In Basketmaker III residence units, pp. 332-355. Unpublished Doctoral dissertation, University of Colorado, Boulder. University microfilms, Ann Arbor.

BRETERNITZ, D. A. 1969. Archaeological investigations in Turkey Cave (NA2520), Navajo National Monument, 1963. Museum of Northern Arizona, Technical Series 8.

_____ . 1970. (Assembler) Archaeological excavations in Dinosaur National Monument, Colorado-Utah 1964-1965. University of Colorado Studies, Series in Anthropology 17.

_____. 1973. Tree-ring dated Basketmaker III and Pueblo I sites in Mesa Verde National Park. Submitted to National Park Service, Midwest Archeological Center, Lincoln.

_____. n.d. Mummy Lake, Mesa Verde National Park. Report in preparation.

BRETERNITZ, D. A. and R. H. LISTER (Assemblers and Editors). n.d. The Morfield Canyon project. Report in preparation.

BURGH, R. F. and C. R. SCOGGIN. 1948. The archaeology of Castle Park, Dinosaur National Monument. University of Colorado Studies, Series in Anthropology 2.

CUTLER, H. C. 1969. Corn and cucurbits from Turkey Cave, NA2520. In Breternitz 1969, pp. 22-26.

CUTLER, H. C. and L. W. BLAKE. 1976. Corn and beans from three Mesa Verde (Colorado) archaeological sites. Appendix in Birkedal 1976, pp. 536-543.

HUSTED, W. M. 1962. A proposed archaeological chronology for Rocky Mountain National Park based on projectile points and pottery. Unpublished MA thesis, University of Colorado, Boulder.

_____. 1964. Pueblo pottery from northern Colorado. Southwestern Lore 30:21-25.

LISTER, R. H. 1951. Excavations at Hell's Midden, Dinosaur National Monument. University of Colorado Studies, Series in Anthropology 3.

_____. 1964. Site 499, Mesa Verde National Park, Colorado. Contributions to Mesa Verde Archeology: I. University of Colorado Studies, Series in Anthropology 9.

LISTER, R. H. 1965. Site 875, Mesa Verde National Park, Colorado Contributions to Mesa Verde Archeology: II. University of Colorado Studies, Series in Anthropology 11.

_____. 1966. Site 866 and the cultural sequence at four villages in the Far View Group, Mesa Verde National Park, Colorado. Contributions to Mesa Verde Archeology: III. University of Colorado Studies, Series in Anthropology 12.

_____. 1967. Site 1086, an isolated, above ground kiva in Mesa Verde National Park, Colorado. Contributions to Mesa Verde Archeology: IV. University of Colorado Studies, Series in Anthropology 13.

_____. 1968. (Assembler and Editor) Emergency archaeology in Mesa Verde National Park, Colorado, 1948-1966. Contributions to Mesa Verde Archeology: V. University of Colorado Studies, Series in Anthropology 15.

MALDE, H. E. n.d. Geological aspects of the Morfield Reservoir. In Breternitz and Lister n.d.

MORRIS, E. H. 1919a. The Aztec Ruin. Anthropological Papers, American Museum of Natural History 26: Part I.

_____. 1919b. Further discoveries at the Aztec Ruin. El Palacio 6:17-23.

_____. 1921. The House of the Great Kiva at Aztec Ruin. Anthropological Papers, American Museum of Natural History 26: Part II.

_____. 1924. Burials in the Aztec Ruin: the Aztec Ruin Annex. Anthropological Papers, American Museum of Natural History 26: Parts III and IV.

_____. 1925. Exploring the Canyon of Death. National Geographic Magazine 48:263-300.

_____. 1928. Notes on the excavations in the Aztec Ruin. Anthropological Papers, American Museum of Natural History 26: Part V.

_____. 1938. Mummy Cave. Natural History 42:127-138.

_____. 1941. Prayer sticks in walls of Mummy Cave Tower, Canyon del Muerto. American Antiquity 6:227-230.

_____. 1948. Tomb of the weaver. Natural History 57:66-71.

_____. 1951. Basketmaker III human figurines from northeastern Arizona. American Antiquity 17:33-40.

RUPPE, R. J. 1966. The archaeological survey: a defense. American Antiquity 31:313-333.

SCOTT, L. J. 1974. Pollen analysis of Mummy Lake. Department of Anthropology, University of Colorado, Boulder, unpublished manuscript.

SIGSTAD, J. S. 1968a. Pipestone carving today. National Parks Magazine 42:16-19.

_____. 1968b. The Catlinite Age and distribution project. Museum Graphic 20:3-6, 11.

SMITH, J. E. n.d. Site 820, Mesa Verde National Park. Report in preparation.

WYCKOFF, D. G. 1974. A pollen profile from Mummy Lake, Mesa Verde National Park, Colorado. Unpublished manuscript prepared for Anthropology 577. Washington State University, Pullman.

_____. 1976. Secondary forest succession following abandonment of Mesa Verde. Unpublished manuscript, Oklahoma Archeological Survey, Norman.

PREHISTORIC SETTLEMENT PATTERNS IN THE BIGHORN CANYON NATIONAL RECREATION AREA, SOUTHCENTRAL MONTANA

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During 1968 through 1976, archaeological reconnaissance work was accomplished in the Pryor Mountain-Bighorn Canyon area of southcentral Montana. The primary goal of the work was to locate archaeological sites that might serve as visitor areas in the Bighorn Canyon National Recreation area and the adjacent Pryor Mountains. Intensive surface survey revealed approximately 450 archaeological sites. Testing has been accomplished on about thirty-five of the sites and excavation has been completed on eighteen sites, including some salvage excavation on sites in the path of a transpark highway. Descriptions of the sites and the artifacts recovered can be found in annual field reports that are filed with the Midwest Archaeological Research Center, National Park Service, Lincoln, Nebraska.

The purpose of this paper is not to describe the sites and artifacts found during the survey. Rather it is intended to describe the settlement pattern that is evident from the spatial distribution of the sites and present the test for that pattern.

As stated by Binford (1968) the aims and goals of American archaeology are to construct culture history lifeways, and process. The spatial arrangement of archaeological sites and the diverse environmental settings in the Pryor Mountain-Bighorn Canyon area offer the prehistorian an ideal situation for research on lifeways. Lifeways research can be pursued within the limits of several theoretical frameworks. The general framework used here is to compare or contrast archaeological sites and their environmental settings.

Studying the distribution of archaeological sites vis-a-vis environmental settings is by no means a new approach to understanding prehistory. Research of this nature has been assumed under the title "settlement archaeology" and described or applied by various prehistorians (see Trigger 1967; Coe and Flannery 1964; Thomas 1970 as examples). Indeed, the approach is not even new on the northwestern plains. Arthur (1966), Frison (1968), or Napton (1966) have all used settlement archaeology in one form or another to describe archaeological phenomena in Montana and Wyoming.

As used in this study, settlements are the archaeological manifestations of communities. Communities are geographic isolates composed of human beings in two or more generations who are interacting; biologically, in signs and symbols, in goods and services, and through the exchange of males and females.

The result of community interaction with the physical environment is a settlement. Settlements may change in size, purpose, or location without changing the concept of community. When the change in settlement size, purpose, or location is identified, a pattern can be sought.

In the Bighorn Canyon area settlements are represented by occupation sites. These sites are located in different environmental settings and initially the Bighorn Canyon area was divided into five life zones to identify the different settings for each occupation site (Figure 1). These zones are recognized mainly on the basis of vegetation. In descending order the zones have been named the subalpine, conifer slopes, juniper breaks, grasslands, and drylands.

Briefly the subalpine zone is located between 8,000 and 8,800 feet elevation. The major vegetation is spruce and fir which are interspersed through open, flat meadows.

The conifer slopes zone consists of limestone canyons and ridges along the sides of the mountains between 8,000 and 6,000 feet elevation. Limber pine is common on most ridges.

The juniper breaks comprise the broken terrain at the heads of the canyons. Juniper or mountain mahogany dominate the zone.

The grasslands are confined to the northern half of the study area. Some streams and their canyons dissect the otherwise flat rolling terrain.

The drylands to the south of the mountains receive about six inches of annual precipitation. Sage and greasewood are the dominant plants.

From the beginning of the archaeological work in the Pryor Mountain-Bighorn Canyon area it seemed likely that the prehistoric peoples practiced a seasonal transhumance similar to that described for other areas on the northwestern plains. Thus, one of the initial aims in the study was to determine the settlement cycle and ultimately test it.

Many small temporary occupation sites were discovered as the survey continued in the Pryor area. Data from these small sites are potentially valuable, but comparison or correlation is difficult due to the paucity of artifacts, lack of features, and absence of good stratigraphy. In an attempt to find some basis for comparison it was proposed that campsite selection criteria be used as classification guides, that is using the criteria the prehistoric residents of the Bighorn Canyon area themselves may have used in selecting a place to camp. Originally, eight criteria were proposed as being those probably used in the selection of a campsite. They were 1) proximity of water, 2) abundance of food, 3) protection from elements, 4) available fuel supply, 5) hiding from enemies, 6) presence of quarrying material, 7) supernatural, and 8) bothersome insects.

Furthermore, it was demonstrated that these criteria could be useful in determining the season that a site was occupied. This was accomplished by recording data on campsite selection for 100 occupation sites in the Bighorn area. Three of the factors--hiding from enemies, supernatural and bothersome insects--could not be keyed and therefore were not used in the study. Each of the other criteria were scaled from one to three. One indicated the absence of an item, two indicated the presence of small amounts of an item, and three indicated that an item was present in significant quantity. For example, if a campsite was situated two or three miles from the nearest flowing water it was assigned the number

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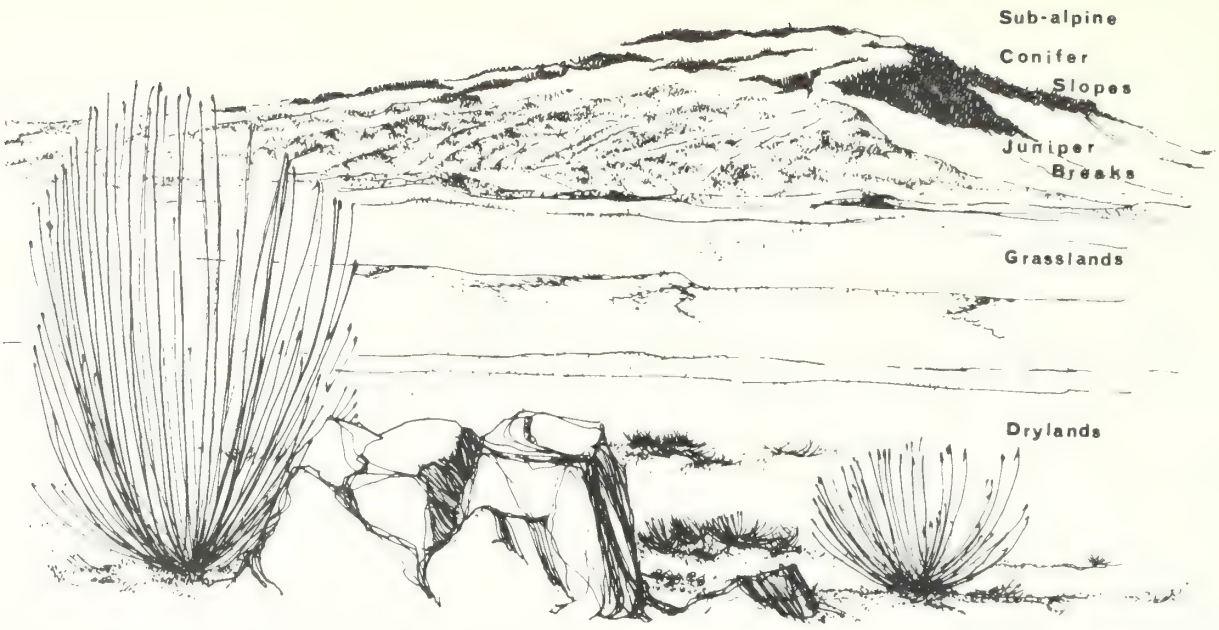

FIGURE 1. Idealized sketch showing the five environmental zones in the Pryor Mountains, Montana.

TABLE 1. Rotated factor matrix (orthogonal).

Variables	Factors 1	2	3	4
Proximity of water	-0.44029	-0.02290	0.03547	-0.05237
Abundance of food	-0.43386	0.49905	-0.28991	0.09683
Protection from elements	0.19614	-0.43746	-0.61732	-0.23125
Available fuel supply	-0.37644	0.23177	-0.56382	0.05881
Presence of quarrying material	-0.29745	0.05294	-0.00322	0.13442
View of surrounding terrain	-0.19490	0.64921	0.17677	0.08102
Size	-0.36734	-0.01707	0.34663	-0.04829
Fire hearth	-0.26791	-0.07990	-0.34662	-0.18320
Tipi rings	0.13151	0.00940	0.38564	-0.24975
Wooden habitation	0.02885	0.06072	-0.47411	-0.01335
Occupied cave	0.10170	0.00162	-0.40725	-0.04025
Lithic debris	-0.72637	-0.07740	0.02890	-0.04151
Sub-alpine	-0.80538	0.32840	-0.11269	0.19360
Conifer slopes	0.02220	0.43707	0.09494	0.65672
Juniper breaks	0.15706	0.20663	-0.11716	-0.89680
Grassland	-0.00284	-0.58739	0.23233	0.22546
Dryland	-0.36780	-0.58045	-0.07282	-0.00446

one. If water were within a mile of a site or the area was good for standing water, it ranked two. If the site was located on the bank of a stream or around a freshwater spring, it rated the number three.

In addition to the five campsite selection criteria eight other variables were recorded for each site and scaled from one to three: 1) view of surrounding terrain, 2) size, 3) presence or absence of fire hearths, 4) presence or absence of tipi rings, 5) presence or absence of wooden habitation structures, 6) presence or absence of occupied caves, 7) amount of lithic debris, and 8) environmental zone.

All data were punched into IBM computer cards, with one card representing each site. The cards were subjected to BMD program X72--a factor analysis program.

Factor analysis was used in this study as an exploratory device. By correlating campsite selection criteria for a number of sites, it was hoped some regularity or pattern could be found. It should be realized that any patterns established by factor analysis are statistical and may not entirely correspond to reality. As David Clarke points out, factors "like all summarizing statistics of relationship, including correlation coefficients...are relationships which may not simply be interpreted as archaeological relationships" (1968:563).

In this study, variables with factor loadings of over .40 in the rotated matrix were selected to have relationships significantly close enough to name the factor. For example, of the variables in Table 1 proximity of water, abundance of food, large amounts of lithic debris and the alpine zone are the variables with a factor loading of over .40. These variables identify Factor One. Three other factors were also identified. A complete discussion of the analysis can be found in Loendorf (1970:17-44), but it is believed that the results of the application of factor analysis to the data involved here from small temporary sites in the Bighorn area reflect the annual subsistence cycle of the prehistoric inhabitants. This cycle is one of seasonal transhumance which is as follows:

The winter months were spent in immovable dwellings (caves and wooden huts) in the sandstone canyons well-protected from the elements. A ready fuel supply for winter warmth was available. Furthermore, it is probable that the winter habitation was a central base to which people returned annually. Archaeologically, this central base is represented by the continuously occupied caves along the Bighorn River (Mangus, Sorenson and Bottleneck Caves). It is also believed that Mummy Cave (Husted n.d.) to the west of the Pryors, and Pictograph Cave (Mulloy 1958) to the north, represent central base occupation.

Unfortunately, the winter-occupied central base cannot be relied upon to propose a tradition. Rather, it must be considered as part of an ecosystem with seasonal fluctuations of resources producing seasonal utilization. In order to propose traditions, it is necessary to consider the entire seasonal movement.

Spring sites (March through June) are represented by small impermanent sites in several environmental zones. With the arrival of spring weather, people appear to have left their well-protected winter sites and moved into other zones to hunt and collect edible plants. Bitterroot was collected along the limestone ridges, and sego lillies were collected in the sandstone and grassland zones.

It is significant that tipi rings, thought to represent a movable dwelling, are most often found in the juniper breaks and grassland zones. Their location would indicate that the time of use of movable dwellings may coincide with the differential ripening times of various plants.

By June and through August the mountaintops of the Pryors have lost their snow cover and present an ideal living place. During the summer months prehistoric peoples took advantage of the quarrying materials and the good hunting on the tops of the mountains. The alpine sites in Factor One represent this summertime occupation. Men would have been hunting and chipping new tools, while women would have been collecting some edible berries and plants and perhaps making new tipi poles from the nearby pine trees.

By late August the peoples were gathering in the grasslands at lower elevations for the annual bison drive. Added to this is the collection of chokecherries for pemmican. After a successful drive and the meat butchered, the people divided to return to their central base for the winter months.

Thus the annual subsistance cycle is one of seasonal transhumance. As a test for this settlement pattern, the relative amounts of the various kinds of flaking detritus on each site were used. Samples of the chippped stone debris were collected from most of the occupation sites found during the eight years of archaeological reconnaissance in the Pryor Mountain-Bighorn Canyon area. The weight of each variety of chipped stone material was calculated and converted into a percentage of the total weight of the flakes in the collected sample. These relative percentages were then compared to the quarry locations for a particular stone material, and when a material decreased in the direction of the proposed movement of the settlement pattern it was suggested to validate the seasonal model.

Several criteria were used in the selection of sites for the test of the seasonal movement model. These criteria included:

1. Only sites with a total weight of 100 grams or more of the chipped stone detritus were used in the analysis. This was done to eliminate sites with inadequate flake collections.

2. Only sites with a variety of flakes were included in the analysis. In other words, although ten or fifteen flakes from the production of one large biface might meet the weight criteria, the site was excluded from the analysis because of lack of variety in the detritus.

3. Since it is believed that after the introduction of the horse, the seasonal settlement cycle deteriorated, single component sites that could be identified as post-horse were excluded.

Approximately 100 occupation sites in the Pryor Mountain area had adequate flake collections to satisfy the requirements listed above. Three of these sites were selected from each environmental zone so that representation of all elevations would be included in the analysis. Another twenty-five sites were picked at random bringing the total to forty sites used in the test.

After converting the weights of each chipped stone material to a percentage of the total weight of the chipped stone detritus on every site, the percentages were recorded in bar graph form with one strip of graph paper representing a site. The strips of graph paper were then ordered according to the hypothetical seasonal model.

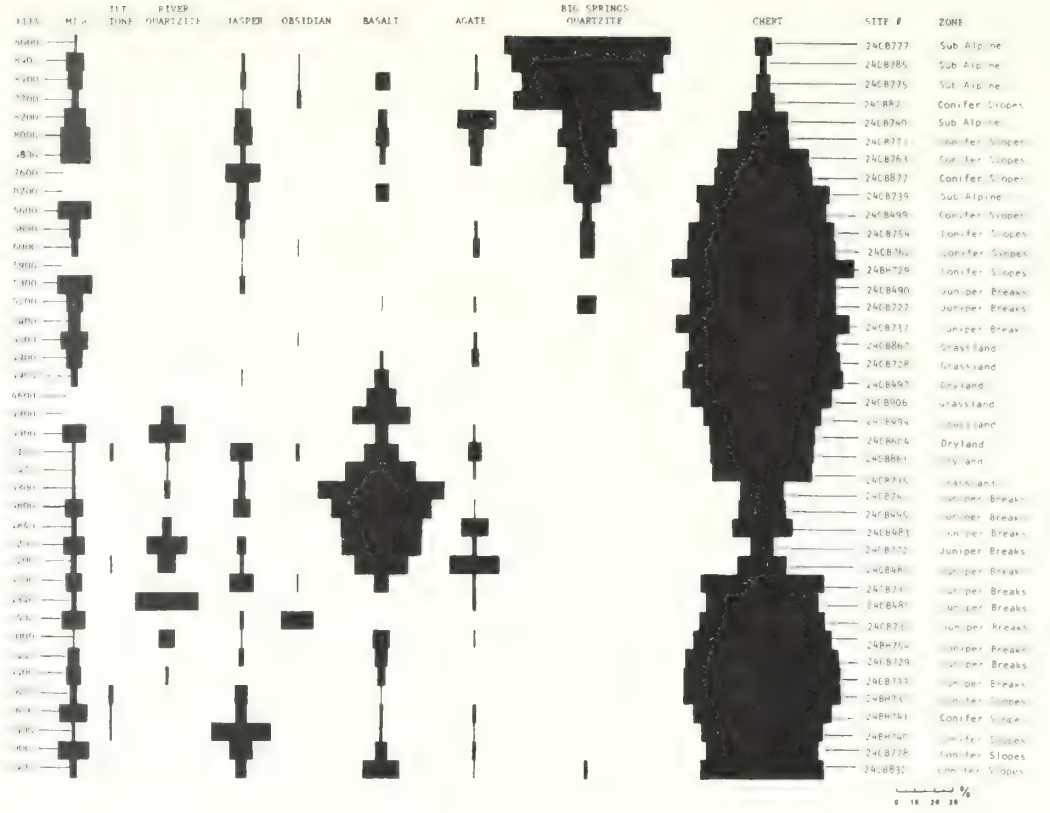

FIGURE 2. Relative percentages of lithic material types plotted according to the settlement cycle.

The procedure outlined above is similar to the technique employed in seriation (Ford 1956). It is important to note that the reasoning behind the use of the technique in a test for movements of chipped stone detritus is different from the reasoning used on normal seriation. Most seriations are dependent on a temporal continuum with a particular artifact type increasing in popularity after its introduction until it reaches a maximum point and then fading as other new types are introduced. The important element in these seriations is the time it takes for an artifact type to begin and complete its popularity cycle.

In the settlement pattern test the relative amounts of chipped stone detritus are dependent upon the location of a site when compared to the locations of different quarries. The element of change in the test is the distance from the quarry to the site. The procurement of lithic material for the production of stone tools is the activity on which the test depends. On all of the sites the flaking detritus represents the residue from the production of stone tools. If people are producing chipped stone tools they must procure cryptocrystalline silicates from their environment. Therefore, on every site where people make chipped stone tools the flakes left behind represent the residue of their efforts. At all times this residue is in an equilibrium with the amount of material available for making the tools. Such an equilibrium is in a stable state as long as the amount of cryptocrystalline material available is in agreement with the needs of the people. When a group of people lived near a quarry they would have had adequate material for the production of stone tools and a stable state equilibrium. But as soon as they move away from the quarry the equilibrium would be altered and the people would have to find new sources of material to make stone tools. As the people move away from a quarry the state of their equilibrium can be labeled dynamic. As defined by Clarke (1968: 50) "a system is said to be in dynamic equilibrium if, in spite of the continuously changing values of its components, at successive points in time, these components closely approximate to a stable state."

If this definition is read to fit the test different cryptocrystalline silicates can be viewed as the components of which the values are continuously changing. By recording the relative amounts of chipped stone detritus on each site we have recorded the values of the changing components. Since these values change as people move away from a quarry, we can determine the direction of the movement.

The graph produced by ordering the sites according to the hypothetical seasonal settlement cycle shows that the movement of lithic materials is in close agreement with the proposed movement in the settlement cycle. The following movement can be ascertained from the graph (Figure 2): movement from the high altitutde quartzite quarries through the jasper quarries and into the chert quarries on the sides of the mountains where there is maximum utilization of chert (sites 24CB777 through 24CB762); movement from the chert quarries to the river bottoms where large amounts of basalt and river quartzite are used (sites 24BH729 through 24CB735); movement from the river bottoms back to the chert quarries on the mountain slopes (sites 24CB741 through 24CB733); and movement from the cert quarries back through the jasper quarries onto the mountaintops (sites 24BH734 through 24CB832).

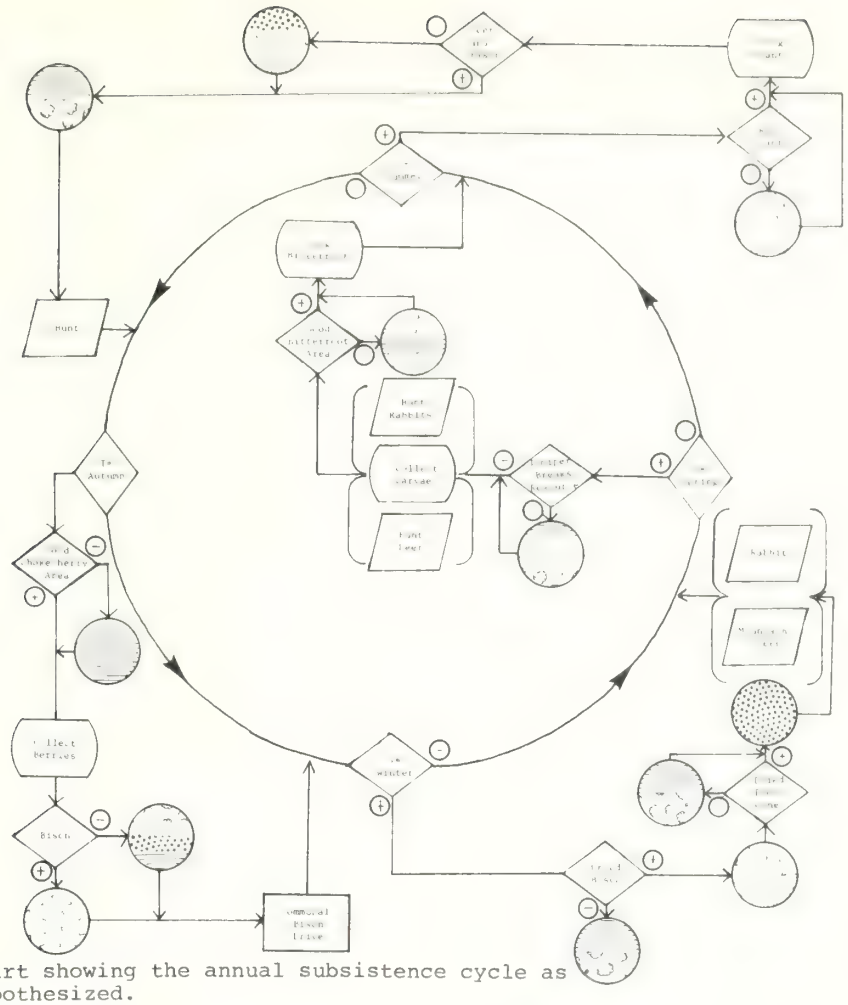

FIGURE 3. Flow chart showing the annual subsistence cycle as it is currently hypothesized.

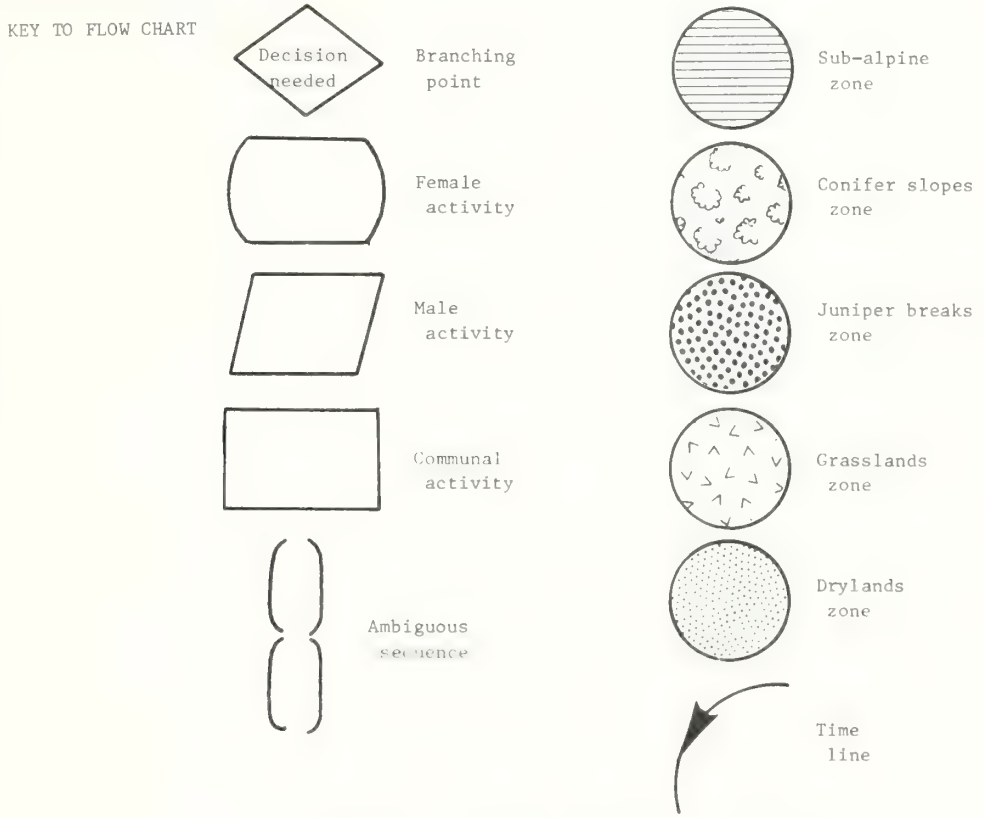

FIGURE 4. Symbols used in the flow chart.

If the movement displayed on the graph is viewed as a model of the proposed movement in the seasonal settlement cycle, then high fidelity between the two has been demonstrated. In this study the real system is unknown, but the fidelity between the suspected system and the model indicates that the real system has been identified. Thus, it is believed that the test validates the hypothetical seasonal settlement cycle.

It should be noted that nothing has been done to indicate the schedule of the movement of the cycle. All the test validates is the movement itself and the order of that movement.

If it is assumed that the prehistoric inhabitants of the Pryor Mountains moved annually through a seasonal transhumance cycle, then scheduling decisions were probably prompted by the differential culmination of resources. The task of the archaeologist is to identify the resources and suggest which combinations of these resources would prompt a move. This task is difficult in the present environmental setting and becomes increasingly more difficult when working with past climatic regimes.

Scheduling decisions were probably made annually, just as today we schedule a new time for deer hunting each year based on the maturity of the herds or we harvest crops at slightly different times each year as they ripen. Likewise the prehistoric peoples in the Pryor Mountains probably made annual decisions that were in agreement with the environmental forces of that year. To identify each of these annual decisions is beyond the scope of the collected data but a pattern can be achieved by summarizing or averaging a series of annual decisions. Once the pattern has been identified, then the task of finding fluctuations in it can begin. Using all the collected data a flow chart of the scheduled activities has been prepared. It is, of course, hypothetical until further field work can be accomplished to test it (Figures 3 and 4).

The specific contribution of this research is not theory, rather it is intended to be in method and technique. It is hoped that the suggested use of chipped stone detritus and campsite selection factors to determine settlement patterns may be of value to other prehistorians. Of course the validity of the approach remains to be tested with additional research in other mountainous areas.

BIBLIOGRAPHY

ARTHUR, GOERGE W. 1966. An Archaeological Survey of the Upper Yellowstone River Drainage, Montana, Agricultural Economics Research Report No. 26, Montana Agricultural Experiment Station, Bozeman.

BINFORD, LEWIS R. 1968. Archaeological Perspectives, New Perspectives in Archaeology, edited by Binford and Binford, Aldine Publishers, Chicago.

CLARKE, DAVID L. 1968. Analytical Archaeology, Methuen and Company, Ltd., London.

COE, M. L., and KENT FLANNERY. 1964. Microenvironments and Mesoamerican Prehistory, Science, Vol. 143, pp. 650-654, Washington.

FORD, JAMES A. 1956. A Quantitative Method for Deriving Cultural Chronology, Pan-American Union Technical Manual No. 1.

FRISON, GEORGE. 1968. Daugherty Cave, Wyoming, Plains Anthropologist, Vol. 13, No. 42, pt. 1, pp. 253-294, Lawrence.

LOENDORF, LAWRENCE L. 1970. Prehistoric Patterns of Campsite Selection in the Pryor Mountains, Montana, Archaeology in Montana, Vol. 11, No. 1, pp. 17-44, Missoula.

MULLOY, WILLIAM T. 1958. A Preliminary Historical Outline for the Northwestern Plains, University of Wyoming Publications, Vol. 22, No. 1, Laramie.

NAPTON, LEWIS K. 1966. Preliminary Archaeological Survey in the Gallatin Area, Montana, M.A. Thesis, University of Montana.

THOMAS, DAVID H. 1970. Prehistoric Subsistence - Settlement Patterns of the Reese River Valley, Central Nevada. Ph.D. dissertation, University of California, Davis, Xerography Copy, University Microfilms, Ann Arbor, Michigan.

TRIGGER, BRUCE G. 1967. Settlement Archaeology--Its Goals and Promise, American Antiquity, Vol. 32, No. 2, pp. 149-160, Salt Lake City.

CURRENT ANTHROPOLOGICAL RESEARCH

GRAND CANYON NATIONAL PARK

Robert C. Euler[1]

Anthropological investigations have been conducted in Grand Canyon National Park for many years--one might almost say since the founding of our Nation in 1776 when the intrepid Franciscan priest, Francisco Garces, recorded the first known European visit to the Havasupai Indians in their village in the depths of Grand Canyon.

Over the decades, especially in the mid-20th century, a considerable amount of research has been conducted so that we now know the basic outline of the cultural history of Grand Canyon--that of its prehistoric inhabitants beginning some 3,000 to 4,000 years ago, as well as that of the historic Indians: the Havasupai, Walapai, Paiute, Hopi, and Navajo.

Most of this research has been sponsored by institutions other than the National Park Service, perhaps because Grand Canyon was always considered a *natural* area with but superficial managerial attention paid to its cultural resources. The park has had research biologists on its staff, but until recently no anthropologist. (Parenthetically, and incredibly, there is no research geologist on the park roster.)

Yet Grand Canyon, unique perhaps in its biological and geological resources, is also unique in its cultural resources--its past and present human inhabitants. Almost 2,000 prehistoric and historic archeological sites representing six major cultural groups have been recorded. Five historic and contemporary Indian tribes have had, and continue to have, an important relationship to Grand Canyon. Perhaps most importantly, the cultural ecology of man's adaption to the beautiful but seemingly inhospitable environments of the canyon is an area of great potential to scientific study.

For the past 2 years, there has been a research *anthropologist* on the National Park Service permanent staff at Grand Canyon and the importance of and support for cultural studies is being more and more recognized. These studies include more than archeological investigations, important though they may be. They also involve those present-day Native Americans I have mentioned, just as important a cultural resource as are prehistoric ruins. Hence, the anthropologist at Grand Canyon has a twofold responsibility:

1) To conduct archeological research and to advise the administration about cultural resource management in the park.

2) To carry out social anthropological studies and to serve as a liaison between the administration at Grand Canyon and the five neighboring Indian tribes.

While funding and facilities for the anthropological research that should be done if management is to fully understand Grand Canyon's cultural resources and the part they play in the long-range administration of the park remain inadequate, some worthwhile investigations are being accomplished.

First of all, in terms of archeological research, work is continuing in the analysis and synthesis of past survey data. This has proceeded beyond the stage of historical reconstruction; we now have a relatively clear understanding of the prehistory of Grand Canyon with only a few major gaps. Thus, we are at a stage of analyzing the records to see what they reveal about past human behavior. This is being done in conjunction with the cooperative activities of the Southwestern Anthropological Research Group (SARG)(Gumerman 1971) and has involved the computerization of data concerning dozens of variables in a standard format from each of 382 archeological sites in the canyon. Hypotheses generated earlier are being tested regarding the general question of "why prehistoric sites are located where they are." These relate primarily to potentially critical resources on which prehistoric people depended. By examining the location of Grand Canyon sites, with respect to the resources considered to be critical for its inhabitants, we are able to test the propositions that:

A. Sites were located with respect to critical on-site resources.

B. Sites were located so as to minimize the effort expended in acquiring quantities of critical resources.

C. Sites were located so as to minimize the cost of resource and information flow between sites occupied by interacting populations (Plog and Hill 1971:12).

Based upon the above statements, it has been specifically hypothesized that:

1) Domestic water was the most critical resource for habitational site locations.

2) Access to the canyon along trails was the second most critical resource.

3) Sites were located with regard to protection from the elements.

4) Food resources, either plant or animal, were not critical to site location.

Invalidation of these hypotheses generally could be interpreted in two ways--either sites were not located with respect to these critical resources, or other, unidentified resources were the critical factors influencing site locations.

Through the use of chi^2 and certain selected statistical analyses such as Pearson's Product-Moment Coefficient, Student's t tests, a specifically generated series of computer maps (MAPSARG), and subprograms from the Statistical Package for the Social Sciences (SPSS) such as REGRESSION and BREAKDOWN (to investigate the central tendencies of critical variables) (Nie et al. 1975), these hypotheses have been tested. A detailed study of these tests (Euler and Chandler 1977) is now in press. Suffice it to say here, these analyses do seem to indicate that the A.D. 1050-1150 Kayenta Anasazi sites in the Grand Canyon were indeed located with respect to those

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environmental variables that have been identified as critical: water and physiographic features that provided protection from the elements. Routes of access also seem to have been an important consideration in Grand Canyon site location. In addition, differences have been found between habitation and limited activity sites with regard to location near critical resources, indicating that different factors influenced the location of different types of sites. A number of additional hypotheses which will give direction to future Grand Canyon archeological research will be tested through the continued use of the SARG data bank. This will be augmented by techniques of locational analysis and the utilization of high altitude LANDSAT imagery with the aim of ultimately arriving at conclusions regarding spatial organization and settlement patterns of the prehistoric populations in Grand Canyon (Effland and Euler n.d.). As will be noted below, however, additional survey especially on the rims of the canyon will be needed to complete the study.

Some of this survey is being accomplished as adjuncts to other projects. For example, archeological reconnaissance of a development area on the North Rim provided some new data (Euler and Chandler n.d.). Contrary to previous suggestions (Schwartz 1970) that the Anasazi occupied that area as early as ca. A.D. 1, our studies would indicate that the earliest Anasazi utilization there appears to have been some several centuries later. It has also been postulated that there were no sites at elevations higher than the Ponderosa Pine zone. Our survey revealed many hunting campsites of both Anasazi and Paiute in and near the higher Alpine meadows.

Farther west on the north side of Grand Canyon in the Tuweep District, continuing studies by Dr. Richard Thompson of Southern Utah State College are providing cultural historical data from that portion of the Arizona Strip. Thompson (1976) has recently completed a stratified random sample survey of 6-8% of three zones totaling 32,000 acres. His fieldwork resulted in the location of 209 sites and a statistical projection of 3,506 for the entire area. Most of these sites were of Virgin Anasazi affiliation and were occupied between ca. A.D. 700 and 1150. Interestingly, no Paiute sites were found in this region of known historic Paiute utilization.

Another, more intensive archeological survey has been accomplished in connection with studies made possible by Public Law 93-620, the Grand Canyon National Park Enlargement Act of January 3, 1975. While this act transferred some 185,000 acres from Grand Canyon National Park and the adjoining Kaibab National Forest to the Havasupai Indian Reservation with absolutely no provision made for a cultural resource inventory (to this author a clear violation of Executive Order 11593), it did generate anthropological research in a 95,000-acre portion of Grand Canyon National Park that has come to be called the "Havasupai Use Lands." Section 10E of the Act permits the Havasupai Indians to use these lands "for grazing and other traditional purposes." The anthropological research, involving ethnohistorical, ethnographic, and archeological techniques, was designed not only to determine the nature of those traditional purposes, but also to provide data germaine to the broader behavioral studies discussed above.

The lands involved in the research are mostly on the Esplanade, that broad shelf of the reddish Supai sandstone some 2,000 ft (610 m) below the South Rim, north of the present Havasuapi Reservation.

At this writing, fieldwork has just been completed and a preliminary report for management purposes prepared (Euler 1976); detailed anthropological analysis is in progress.

Although more than 100 historical documents and maps relating to the Havasupai, dating from 1665 to 1900, were examined (Euler 1973, 1974), none provided any useful data concerning the lands under consideration. Earlier ethnographic studies (Cushing 1882; Spier 1928) revealed little information. The unpublished study of the habitat of the Havasupai by the anthropologist and ethnobotanist Alfred Whiting, fieldwork for which was accomplished in 1940-41, however, had much to say about Havasupai use of the Esplanade for limited grazing, the hunting of mountain sheep as well as other animals, and the gathering of many wild edible plants, especially *Agave* (Whiting n.d.). Ethnographic fieldwork in the spring of 1976 (author's field notes) was curtailed by Havasupai Tribal Council concerns; what was accomplished with older respondents supported Whiting's conclusions.

To provide additional data and to check ethnographic statements, an intensive archeological survey of the area was carried out in the spring and fall of 1976. This was done in this roadless area by helicopter, with landings made at virtually every evidence of past human utilization encountered as well as at a number of locations undisturbed by human activity.[2] Cultural remains were easily visible from the air, their features standing out in sharp contrast to the surrounding natural landscape. At each site, photographs and other records were made and *controlled* surface collections of artifacts were gathered for later laboratory analysis. While this analysis has not yet been completed, enough has been done to enable an accurate cultural and temporal placement of most sites.

A total of 177 archeological sites was recorded during the survey; analysis of diagnostic ceramic remains has been completed for 130. This indicates that 71 were affiliated with the prehistoric Cohonina cultural tradition, 18 with the Cerbat (Havasupai) culture, 10 with the Kayenta Anasazi tradition, four which possibly relate to the Southern Paiute, one occupied by peoples from the Prescott area, one Anglo-American food cache, and 25 yielding insufficient diagnostic cultural material to make an association possible.

Further analysis revealed that the Cohonina people were the first to utilize this portion of the Esplanade, beginning about A.D. 850 or slightly earlier. Six Cohonina sites date between A.D. 850 and 1050; the remainder were occupied between A.D. 1050 and 1150. All of the Kayenta ruins were similarly occupied in the A.D. 1050-1150 period, as was the one Prescott tradition site. The Cerbat (Havasupai) sites were in use only after A.D. 1300 and, according to the archeological evidence at any rate, most of these before A.D. 1600. A few were utilized during the latter part of the 19th century and the presence of a few rifle shell casings indicate Havasupai presence in the 20th century. It must be emphasized that these dates are based at present primarily upon datable ceramic design elements; after ceramic containers were no longer in use, it is more difficult to

[2]Appreciation is expressed to Gloria K. Euler, Collaborator in Archeology at Grand Canyon National Park for her field and laboratory assistance in this project.

place a Havasupai site temporarily. The few possible Southern Paiute sites were constructed only after A.D. 1300 and utilized for an indefinite but probably limited time span. The Anglo-American food cache was placed under a large rock probably sometime in the 1950's.

The great majority of archeological sites in this section of the Esplanade consisted of mescal pits and associated rock shelters that once were inhabited by people on a seasonal basis as they hunted and gathered over the land. At the 130 sites so far analyzed, 206 mescal pits and 64 inhabited rock shelters were recorded. In addition, there were 63 masonry habitation rooms, most of these marked by crude, dry-laid walls of one or two courses high inside the natural rock shelters. Only one habitation site with well-constructed masonry walls, that of the Prescott tradition, was noted. Seventeen masonry granaries or storerooms built under overhanging ledges of the sandstone were also recorded. From the analyses so far completed, it would appear that all cultural groups utilized the Esplanade for the same general economic purposes: the gathering and roasting of *Agave* and other edible wild plants, and the hunting of mountain sheep (the bones and horns of which were noted at some sites), deer, and smaller game animals. Once the accumulated survey data are computer-coded in the SARG format, additional analyses will be carried out.

Another archeological project at Grand Canyon is receiving continuing attention. This is the analysis of cultural and biological materials excavated in Stanton's Cave, a deep solution cavern in the Mississippian Redwall limestone formation of Marble Canyon. Excavations there were conducted in 1969 and 1970 (Euler 1975), under the sponsorship of the National Geographic Society, for two primary reasons:

1) To attempt to locate diagnostic artifacts in direct association with Desert Culture split-twig figurines in order to determine the cultural affinities of the latter.

2) To obtain a stratigraphic biological record from the cave deposits to reconstruct a paleo-environmental sequence in Grand Canyon.

While 65 figurines were recovered, all from the upper 5 cm of the fill, no other artifacts were found in association. The author's earlier postulate (Euler and Olson 1965) that the twig figures were associated with the Pinto Basin culture remains hypothetical.

The biological remains recovered yielded important data which, when placed in relationship to the radiocarbon dates obtained, extend back more than 35,000 years. In lower levels, Pleistocene birds and animals were found in association with dominant *Artemisia* and *Juniperus*, indicating a cooler, more moist climate than exists at present. Upper levels, younger than 10,000 B.P. revealed modern fauna and a more xeric climate.

In the hope of achieving more precise temporal controls for these climatic changes, geologists from the U.S. Geological Survey Central Environmental Studies Branch, Black-Mesa-Four Corners Project, under the direction of Thor N. V. Karlstrom, have recently taken soil samples from strata at Stanton's Cave for paleo-magnetic dating. Preliminary results have indicated definitely reversed polarity characteristics, and the geologists plan to collect additional samples in the near future. This is but part of a larger Geological Survey project (for which the author is serving as archeological consultant) that ultimately aims at the reconstruction of the paleo-climatic record of the Four Corners country of the Southwest, including Grand Canyon. So far, important correlations between this record and the archeological continuum on Black Mesa, east of Grand Canyon, have been published (Karlstrom et al. 1976). These environmental episodes probably were important factors in prehistoric culture change in Grand Canyon as well. Parenthetically, this multidisciplinary design to solve related problems serves not only as an excellent example of the value, importance, and indeed the necessity for such a scholarly approach, but also points out the dynamics of what can be accomplished through federal interagency cooperation.

Related to the search for the identity of the Archaic split-twig figurine makers, archeologists and a botanist from the Arizona State Museum, the Museum of Northern Arizona, and Grand Canyon National Park recently investigated another Grand Canyon cave containing these artifacts. In July 1976, 17 figurines and a wooden "spatula-like" object were collected under carefully controlled conditions from Mother Cave (site Ariz. B:16:84 in the Grand Canyon National Park Archeological Survey records). The wooden object most closely resembles a bull-roarer but shows no evidence of use. While again, no diagnostic cultural remains were found in association with the figurines, some new data were noted. At the time the figurines were deposited in the cave, some 3,000 to 4,000 years B.P. according to radiometric determinations from similar speciments (Euler and Olson 1965), pieces of previously accumulated pack-rat midden were broken from larger masses and placed over the caches of figurines.

The botanical component of these pack-rat middens is currently being analyzed by Arthur Phillips of the Museum of Northern Arizona. In addition, while the figurines conform generally to others previously described, it has been determined (Hevly, personal communication) that they were constructed from two separate plant species, cottonwood (*Populus fremontii*) and willow (*Salix* sp.), and probably during a season of the year from late fall to early spring as determined by the presence of winter buds on the twigs.

It is clear that while advances are being made in archeological investigations at Grand Canyon, more research must be done before the cultural dynamics of past human populations there are understood. As was emphasized a few years ago (Euler 1974), Inner Canyon settlement patterns were undoubtedly closely related to those on the rims of the canyon. It is estimated that almost 500,000 acres of Grand Canyon National Park, mostly rim areas, have not been surveyed archeologically (let alone biologically). Research designs, emphasizing stratified random as well as judgment sampling, should be formulated. Indeed, such have recently been proposed for areas of northwestern Grand Canyon being studied for possible future inclusion in the National Park (Lipe and Thompson 1976). These designs must be followed by field survey, not only to begin to bring Grand Canyon National Park into compliance with Executive Order 11593), but more importantly, in the author's opinion, so that scientific research goals may be achieved. Furthermore, as has also been urged (Euler 1974), selected and limited excavation in some 10 archeological sites should be funded and carried out. These specific excavations are keys to both the major gaps in the cultural historic record and cultural ecological aspects of human adaptation to Grand Canyon. Parenthetically, suggestions that archeological excavations in national park areas should be undertaken only if they relate to administrative development programs, and thus with no regard to basic research goals, are without

scientific substance and acumen and as such are deleterious to sound scientific advances.

Research in social anthropology at Grand Canyon is by no means so far advanced as that in archeology. Aside from the ethnographic and ethnohistoric studies with the Havasupai already discussed, little is being done. Paradoxically, a dynamic research program especially in the applied aspects of social anthropology is probably more crucial than one in prehistory.

The National Park Service at Grand Canyon has relationships with five neighboring tribes--Walapai, Havasupai, Navajo, Southern Paiute, and Hopi; Grand Canyon shares common boundaries with the first three. These relationships, it is fair to say, are not the most harmonious. One anthropologist, attempting to act as a liaison, interpreting Indian attitudes and desires to federal officials and explaining federal positions to the Indians, is not a program! The problem of intercultural relations is apparent. It is also complex and has been compounded by years of misunderstanding, mistrust, and basic prejudice. Changes in Indian and National Park Service leadership, accompanied by changes in programs, policies, and attitudes, not to mention what may realistically be viewed as benign neglect on the part of the latter, have created this conflict. The only way, in this author's view, that this conflict may be eased--and it must be eased--is through mutual understanding (and especially so on the part of Government administrators) of basic principles of human relations (see, for example, Leighton 1946), acculturation, the relativity of value systems, and other tenets so fundamental to an anthropological approach to solving intercultural problems.

LITERATURE CITED

CUSHING, FRANK H. 1882. The Nation of the Willows. The Atlantic Monthly. L:CCXCIX.

EFFLAND, RICHARD and ROBERT C. EULER. n.d. Spatial Organization and Settlement of the Prehistoric Population of the Inner Grand Canyon, A.D. 1050-1200. Manuscript in preparation.

EULER, ROBERT C. 1973. Havasupai of Arizona, 1150-1890. New York: Clearwater Publishing Co.

_____. 1974. Havasupai Historical Data. New York: Garland Publishing Co.

_____. 1975. Archeological and Paleo-Biological Studies at Stanton's Cave, Grand Canyon National Park, Arixona: A Progress Report. National Geographic Society Research Reports. In Press.

_____. 1976. Cultural Patterns in the Havasupai Use Lands, Grand Canyon National Park. Manuscript.

EULER, ROBERT C. and SUSAN M. CHANDLER. n.d. Aspects of the North Rim Archeology, Grand Canyon. Manuscript in preparation.

_____. 1977. Aspects of Prehistoric Settlement Patterns in Grand Canyon. Manuscript.

EULER, ROBERT C. and ALAN P. OLSON. 1965. Split-Twig Figurines from Northern Arizona: New Radiocarbon Dates. Science 148:368-369.

GUMERMAN, GEORGE J. 1971. The Distribution of Prehistoric Population Aggregates. Prescott College Anthropological Reports No. 1. Prescott, Arizona

HEVLY, RICHARD. 1976. Personal Communication, October 29.

KARLSTROM, THOR N.V., GEORGE J. GUMERMAN, and ROBERT C. EULER. 1976. Paleo-environmental and Cultural Correlates in the Black Mesa Region. In Gumerman, George J. and Robert C. Euler (eds.). Papers on the Archeology of Black Mesa, Arizona. Carbondale: Southern Illinois University Press.

LEIGHTON, ALEXANDER. 1946. The Governing of Men. Princeton: Princeton University Press.

LIPE, WILLIAM D. and RICHARD THOMPSON. 1976. Some Considerations for Assessment of Potential Additions to Grand Canyon National Park. Manuscript.

NIE, NORMAN H., C. HADLAI HULL, JEAN G. JENKINS, KARIN STEINBRENNER, and DALE H. BRENT. 1975. Statistical Package for the Social Sciences. 2nd ed. New York: McGraw Hill.

PLOG, FRED and JAMES N. HILL. 1971. Explaining Variability in the Distribution of Sites. In Gumerman, George J. (ed.) The Distribution of Prehistoric Population Aggregates. Prescott College Anthropological Reports No. 1. Prescott, Arizona.

SCHWARTZ, DOUGLAS W. 1970. Grand Canyon Archeological Research. Manuscript.

SPIER, LESLIE. 1928. Havasupai Ethnography. Anthropological Papers of the American Museum of Natural History XXIX. New York.

THOMPSON, RICHARD A. 1975. A Projection of Archeological Site Densities in the Slide Mountain, Tuckup Point, and Jensen Tank Areas of the Grand Canyon National Park. Manuscript.

WHITING, ALFRED. n.d. Havasupai Habitat. Manuscript.

ETHNOHISTORY OF THE KALTAG PORTAGE, WEST CENTRAL ALASKA

Elizabeth Andrews and Kathryn Koutsky[1, 2]

INTRODUCTION

The Kaltag Portage, extending over 80 miles between Kaltag on the Yukon River to Unalakleet on Norton Sound in the Bering Sea region, provides the shortest overland route between the coast and the interior of west central Alaska. The portage was a traditional trade route between the Yukon River and Norton Sound for native products well into the twentieth century and was used by agents of change throughout Alaskan history. Heavily utilized for the expansion of the Russian fur trade, the development of American institutions, and the gold rushes, the history of the portage thus represents a case study illustrating culture change in west central Alaska.

THE KALTAG PORTAGE AND NATIVE ALASKANS

Spanning the narrow stretch of land between the glacial waters of the Yukon River and the saltwaters of the Bering Sea, the Kaltag Portage crosses overland following the transition from the subarctic boreal forest on its river terminus at Kaltag to the lake-studded coastal tundra lowlands bordering the Bering Sea at Unalakleet (Figures 1 and 2). During the past 150 years two major cultural groups--Indians and Eskimos--have occupied and utilized the portage. Athapaskan-speaking Indians occupied the subarctic boreal forest and Unalit Yupik-speaking Eskimos lived on the coast and lower stretches of the Unalakleet River.

The Indians relied predominantly on salmon as a staple with caribou, bear, beaver, muskrat, and birds also of importance (Loyens 1966:36). The Eskimos followed a small sea-mammal subsistence pattern, dependent on the sea to provide a variety of seal and beluga, while they also utilized the inland environment for caribou, fish, migratory waterfowl, ptarmigan, rabbits and squirrel (Ray 1975:104). The different environments occupied by these two groups provided different products which were exchanged via the Kaltag Portage. Indians and Eskimos both lived along the portage itself and the boundary between these two groups fluctuated. From the mid-nineteenth century on, however, Lower Koyukon Indian territory extended west along the portage as far as the Chiroskey River, only 17 miles east of the Eskimo village of Unalakleet (Loyens 1966:12). Although these two groups occasionally intermarried and shared the same villages along the portage route, they also have an oral literature rich in tales of battles and brief skirmishes between them. Important items provided by the Eskimos included sea-mammal products such as seal oil, beluga sinew, and ugruk skins for waterproof boot soles which were exchanged for furs and other interior forest products. The Eskimos along the Bering Sea coast traded with the Siberian coast, exchanging furs for reindeer skins, tobacco, iron and tea (Ray 1975:97-102). These mutually advantageous trade relationships were jealously guarded.

EARLY HISTORIC PERIOD (1833-67)

The Russian-American fur trade companies were anxious to expand their trade into the interior and coastal areas of west central Alaska. The earliest recorded history of the Kaltag Portage coincides with the establishment of the Russian post at St. Michael in 1833. Fredinand P. von Wrangell, Governor of the Russian American colonies, was determined to establish communications overland between the Bering Sea and interior Alaska to intercept the native traders and to destroy their monopolies. To achieve this end, he sent Mikhail D. Tebenkov to Cape Stephens to build the Russian post, Mikhailovski, or Fort St. Michael (Brooks 1973:229; Ray 1975:122). From this post Andrei Glazunov, a Russian creole, was sent to explore the Yukon. He made two trips overland, but it was not until 1837 that he was guided east from Unalakleet along part of the Kaltag Portage, arriving at an Indian village on the Yukon, 42 miles below Kaltag (Michael 1967: 81, 135, 359).

The following year a Russian-American trading post was established by Vasilly Malakhov at Nulato on the Yukon, 35 miles above Kaltag, the western terminus of the portage. As long as the Kaltag Portage remained undiscovered, the Russian trading posts, located at Nulato, Unalakleet and St. Michael, could not intercept the native trade. In February, 1838, Malakhov crossed part of the Kaltag Portage from Unalakleet to the Yukon terminating at an Indian village 28 miles below Kaltag (Michael 1967:138). On a second journey the next fall, Malakhov again was guided by a Lower Koyukon Indian trader along a portion of the portage route, this time terminating 42 miles below Kaltag on the Yukon. Malakhov grew suspicious and succeeded in calculating the actual route of the portage which terminated near Kaltag (Michael 1967:82). Finally in January 1843, Lt. L. A. Zagoskin determined for the Russian-American Company the shortest and most practical route between Unalakleet and the Yukon River--the traditionally native-used Kaltag Portage (Michael 1967:141). This achievement allowed the Russians to efficiently transport along the portage the furs which they intercepted at the Nulato post only 35 miles above Kaltag. However, native trade still continued and the Russians were only partially successful in breaking the native monopoly (Michael 1967).

The Russian discovery of the Kaltag Portage in 1843 enabled the Western Union Telegraph Company of the United States, over 20 years later, to survey and construct a line which would connect the eastern and western hemispheres of the world (Anonymous 1867-68:216). Receiving permission from the Russian government to cross Russian America, the American naturalist Robert Kennicott was asked to conduct the survey for the route. In the winter of 1865-66 he sent a party from Unalakleet across the portage to Nulato. Although Kennicott died the following spring at Nulato, naturalist William Dall and the remainder of the survey party established a portion of the telegraph route along the portage. On July 25, 1867, Dall received news at Nulato of the success of the Atlantic cable and the overland telegraph project was abandoned (Dall 1970:119). Even

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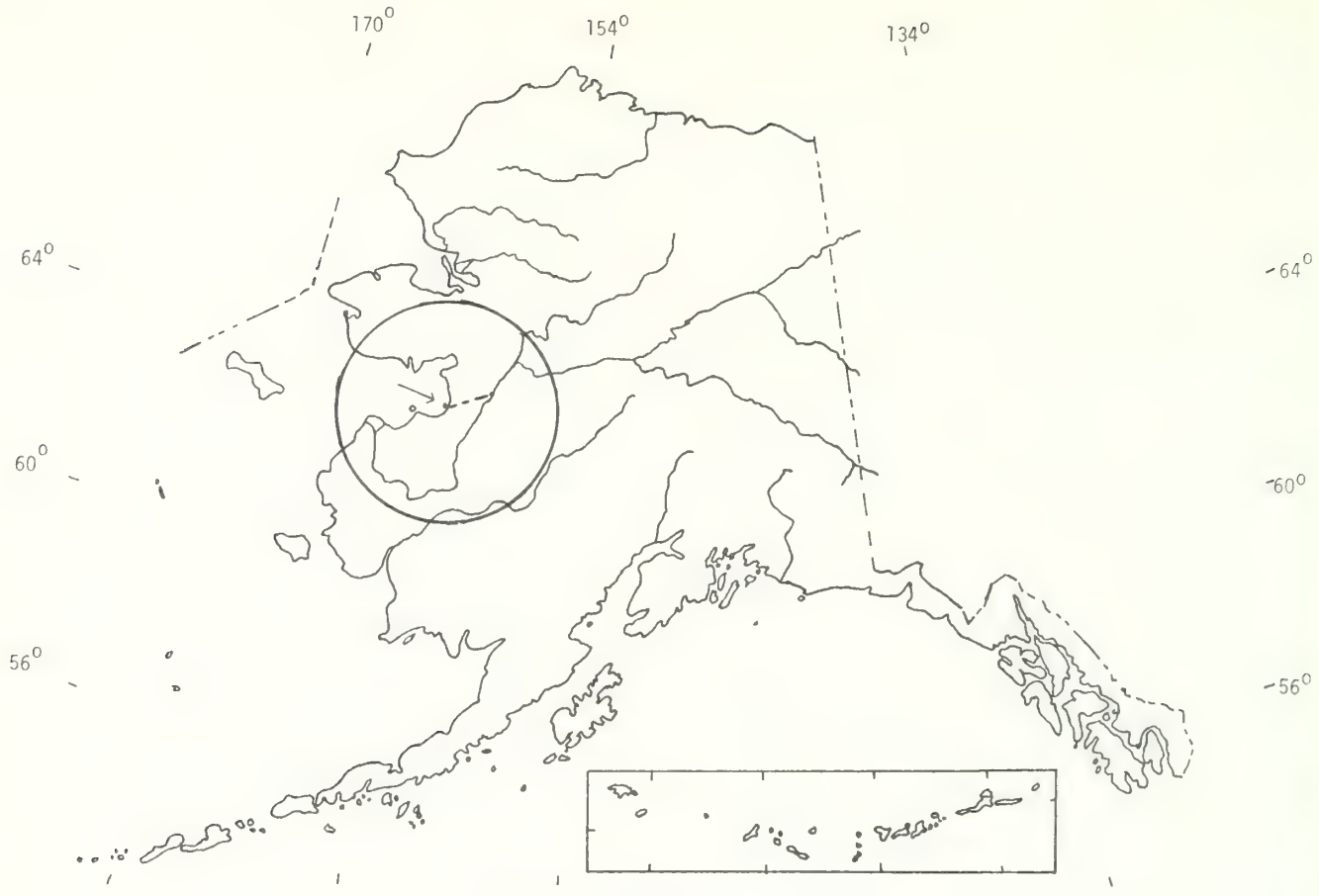

FIGURE 1. Situation in Alaska.

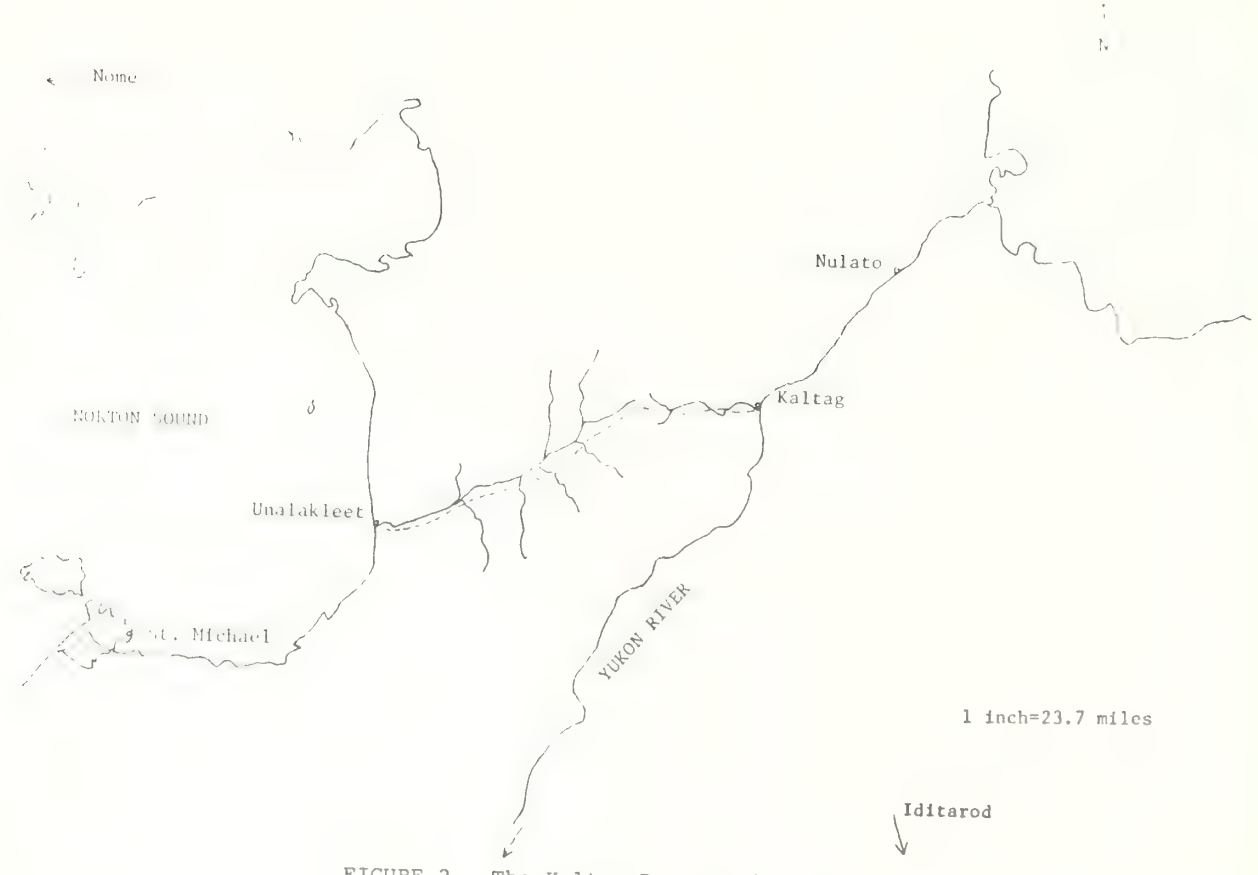

FIGURE 2. The Kaltag Portage (------).

though the telegraph project was abandoned, the portage was officially recognized as the shortest practical route for modern communication systems which were established in the early twentieth century.

HISTORIC PERIOD (1867-1925)

The major change that occurred following the purchase of Russian-America by the United States in 1867 was the transfer of the Russian-American trading posts to the American firm of Hutchinson, Kohl and Company, later to become the Alaska Commercial Company (Brooks 1973:110). The ambitious Americans soon affected the traditional use of the portage in two critical ways: they expanded fur trade competition with each other to the advantage of the native traders and introduced steam-powered sternwheelers to the Yukon River (Kitchener 1954:148). By 1868, Hutchinson, Kohl and Company established themselves at former Russian posts including St. Michael on Norton Sound and Nulato on the Yukon (Brooks 1973:269). The sternwheeler *Yukon* was introduced to the river this same year and was the first of what was to become a substantial fleet carrying supplies for American traders and miners along the Yukon. The use of these large boats allowed larger quantities of goods to be efficiently transported upriver, shifting the emphasis from a short overland route between the coast and interior to an all-water route. Nonetheless, the Kaltag Portage continued to be used by Indians and Eskimos for native trade, while native traders continued to occupy villages along the portage route.

Gold rushes of the late nineteenth and early twentieth centuries produced an explosion of frenzied activity in west central Alaska. Traditional native life was dramatically altered with the influx of white miners. The boom and bust of gold mining towns demanded better communications and transportation. There were three major gold strikes that affected the portage area around the turn of the twentieth century--the Klondike strike of 1897, the Nome rush from 1898 to 1900, and the Iditarod strikes beginning in 1906. The gold rush brought increased commercial activity to the river trade and transportation business. Most of the major freighting of supplies and passengers occurred in the summer on the river. By 1900, 46 steamers and 46 barges operated by at least 6 separate companies plied the waters of the Yukon (Cantwell 1902:280-281). Unlike pre-gold rush days, the use of the Yukon as a summer transportation corridor did not decrease the importance of the portage as a winter route. Use of the Kaltag Portage as the overland route from the Yukon to the gold fields in Nome peaked in the winter of 1899-1900 when over one thousand miners used the portage as part of the direct winter route between Dawson, the Yukon valley and Nome (Jackson 1900:13). Miners traveled the portage during all seasons using dog teams, mules, horses, rafts, and even bicycles (Jackson 1899, 1900). Indians and Eskimos also continued their use of the portage for trading activities. By 1908, official recognition of the need for a clearly marked trail between the Gulf of Alaska in the Pacific and Norton Sound in the Bering Sea became evident. The Alaska Road Commission surveyed the route using existing trails including the Kaltag Portage (Bureau of Outdoor Recreation 1975). The trail was completed in two years.

Occurring simultaneously with the gold rush and commercial company expansion, schools and missions brought foreign education, religion, and reindeer herding to the natives. Two major missions with schools were established near the portage--the "Swedish Covenant" among the Eskimos at Unalakleet and a Catholic mission for the Indians at Nulato. The evangelical church of Sweden sent Axel Karlson to St. Michael where he met the Eskimo Nashalook from Unalakleet. Nashalook asked Karlson to locate the mission and school at his home village. Karlson arrived in Unalakleet in 1887 and established both a church and school for the Eskimos by 1889 (Almquist 1962: 57). The influence of western education was extended to natives living on the portage when Eskimos from neighboring villages and Indians from their westernmost village on the Kaltag Portage requested additional schools be located in their communities (Ray 1975:212).

Unlike the Swedish mission at Unalakleet, the Catholic mission at Nulato developed as a result of trading problems occurring at the village where the trading post brought many Indians into the area. In the 1870's trade competition between commercial companies grew so intense that fur traders were paying more to the Indian trappers than they were making by selling the furs in San Francisco (Kitchener 1954:149). The tension which developed between the traders and Indians drove the chief trader to the home office in San Francisco where he requested the presence of Jesuit priests to bring order and religion to his customers (Kitchener 1954:148). By 1888 the Jesuits had established a church and center for operations at Nulato (Loyens 1966:117). Thus, with the establishment of two active missions near the portage, people gravitated to them to take advantage of new opportunities. The villages along the portage consolidated into one and overall population decreased.

Reindeer herding was introduced to mainland Alaska in 1892 by Sheldon Jackson, General Agent for Education. Incorporating herding into the existing school and mission system, Jackson hoped to prevent what he believed to be periodic starvation among the Eskimos. The gold rush and expanding commercial interests shifted his emphasis from the Eskimos to the commercial importance of reindeer to miners for transportation and as a food source (Jackson 1897:12-14). Eaton Reindeer Station near Unalakleet was established in 1897-1898. The location was chosen for its good reindeer foraging grounds as well as its proximity to both the coast and interior via the Kaltag Portage. It was hoped that locating the station in the vicinity of the leading missions would provide young native men to be trained as herders (Jackson 1897:9). The Kaltag Portage was the route used to transfer herds from the coast to the interior. For example, the Catholic mission at Nulato received 100 deer in 1901 from Unalakleet and reindeer were also driven to the mining town of Iditarod supplying fresh meat.

At this same time the portage was used as a communication corridor with dog-mushing mailmen and occasionally reindeer-drawn sleds providing postal service to the new American population. Despite the establishment of post offices at St. Michael, Unalakleet, Kaltag and Nulato, mail service in west central Alaska was unorganized and irregular. At first, mail was sent and received by whatever transportation means possible. During the summer, steamers carried mail while in the winter overland routes, such as the Kaltag Portage, were utilized to deliver mail to the news-hungry miners. Eventually mail was carried regularly between St. Michael and Kaltag once a month by dog team (Jackson 1899:90). As late as the 1920's, seventy-five percent of all winter mail was still carried by dog sled (Bartlett 1963: 2), and native informants recall contracting to transport mail across the Kaltag Portage.

However, mail was a slow and inefficient means of communication. With the influx of miners during the gold rush, army posts were established to maintain order. It took a year to send a message and receive a reply from Washington, D.C. Therefore, in 1900, the U. S. Army Signal Corps began construction of the Washington Alaska Military Cable and Telegraph System (WAMCATS) to connect military posts and for commercial use. By 1901, the line was completed from St. Michael to the Unalakleet across the Kaltag Portage to Fort Gibbon at Tanana (U. S. Army 1969:49). By 1903, this telegraph line linked communities in the new territory with each other and the rest of the world.

The last major event that occurred along the portage was the serum run of 1925. In February of that year, Nome was struck with an outbreak of diphtheria which threatened to reach epidemic proportions. The antitoxin at Nome was over six years old and useless. Although Anchorage had a supply, air transport of the antitoxin was impossible as the three airplanes in the territory had been stored for the winter. Frozen river and sea waters prevented transportation by water. The only possible solution was a relay by dog team to Nome from the railhead at Nenana on the Tanana. In a record-breaking ordeal, eighteen dog mushers relayed the serum down the Yukon, across the Kaltag Portage to Norton Sound thence to Nome (Bartlett 1963). The potential disaster was averted.

In conclusion, as the shortest overland route from the coast of Norton Sound to the Yukon River in interior Alaska, the Kaltag Portage facilitated contact and change in west central Alaska. During the nearly ninety-year period from 1833 to the 1920's use of the portage varied in intensity as differing waves of change appeared. Traditionally, as an exclusively native-used trade route, Eskimos and Indians exchanged goods and maintained a monopoly in the fur trade which extended from the Yukon River west to Siberia. The Russian-American Company later established posts at St. Michael on Norton Sound and Nulato on the Yukon in an attempt to intercept that flourishing trade. For nearly a decade after the presence of Russians in west central Alaska, the natives succeeded in maintaining their monopoly, misguiding Russian explorers to the Yukon thereby concealing the Kaltag Portage. With the subsequent Russian discovery of the portage the Russian-American Company was able to enter the native trade network and more effectively undermine the Alaskan-Siberian trade. In addition, this trade route was revealed as an important communication corridor which was opened with the American survey for the Western Union Telegraph Company.

With the transfer of Alaska to American jurisdiction in 1867, commercial companies were established at formerly Russian posts. By using steam-powered sternwheelers along the Yukon, Americans shifted the emphasis from the traditional overland route along the portage to the Yukon waterway. With the discovery of gold, steamboats provided an efficient means for transporting large numbers of people and supplies inland during the ice-free season. Still, as the shortest overland route between the coast and interior, the Kaltag Portage remained an avenue of communication. The mail system and the military telegraph line developed in response to the new influx of Americans into Alaska. As part of the American expansion, missions, schools and reindeer herding were established to bring a new way of life to the natives. As people moved to larger settlements to take advantage of these new opportunities, the villages along the portage were abandoned. The Kaltag Portage, however, persisted as a route for Eskimo-Indian exchanges. Thus, from the commerce of the Russians to the transportation and communication necessary for American expansion and development, the Kaltag Portage served as a means for bringing multiple changes to west central Alaska.

REFERENCES

ALMQUIST, L. 1962. Covenant Missions in Alaska, 1887-1962. Covenant Press, Chicago.

ANONYMOUS. 1867-68. The Journal of Robert Kennicott. Transactions of the Chicago Academy of Sciences, Vol. 1, No. 2, pp. 132-226.

BARTLETT, E. L. 1963. Man and Dog: The Mail Goes Through, Congressional Record, Vol. 109, No. 145, pp 1-5, Washington.

BROOKS, A. H. 1973. Blazing Alaska's Trails. University of Alaska Press, College.

BUREAU OF OUTDOOR RECREATION. 1975. Seward-Nome Route. Alaska Gold Rush Trails Study. U. S. Department of Interior, Anchorage, Alaska.

CANTWELL, J. C. 1902. Report of the Operations of the U. S. Revenue Steamer Nunivak. Washington.

DALL, W. H. 1970. Alaska and Its Resources. Arno and the New York Times, New York.

JACKSON, S. 1897. Report on the Introduction of Domestic Reindeer into Alaska. U. S. Office of Education, Washington.

_____. 1899. Ninth Annual Report on the Introduction of Domestic Reindeer into Alaska. U. S. Office of Education, Washington.

_____. 1900. Tenth Annual Report on the Introduction of Domestic Reindeer into Alaska. U. S. Office of Education, Washington.

KITCHENER, L. D. 1954. Flag Over the North. Superior Publishing Company, Seattle.

LOYENS, W. 1966. The Changing Culture of the Nulato Koyukon Indians. University Microfilms Ann Arbor.

MICHAEL, H. N. (ed.) 1967. Lieutenant Zagoskin Travels in Russian America, 1842-44. University of Toronto Press, Toronto.

RAY, D. J. 1975. Eskimos of the Bering Strait, 1650-1898. University of Washington Press, Seattle.

U. S. ARMY. 1969. The Army's Role in the Building of Alaska. U. S. Army, Alaska.

ARCHAEOLOGICAL SAMPLING TECHNIQUES IN ALASKA

Harvey M. Shields[1]

Alaska is a large and virtually untapped reservoir of archaeological information. Because of the climatic rigors and logistical problems that are encountered while working in Alaska, all but the most dedicated have left arctic research alone. Now, with the divvying up of the land by the Alaska Native Claims Settlement Act, it is necessary to survey large areas in order to comply with various federal historic preservation laws. This provides the opportunity for a more complete understanding of Alaskan lifeways through time. To take advantage of this opportunity, methods and techniques must be applied that will maximize data for scholars interested in the study of circumpolar man and for the managers whose trust it is to look after and care for the archaeological resource. It is the purpose of this paper to report on one such technique and how it relates to the scholar, as well as the manager.

Most archaeological surveys in Alaska tend to be carried out on an intuitive basis (for example, Bacon 1971; Borass 1971; Clark 1975; Cook 1971; de Laguna 1934; Holmes 1971; Powers 1975). One goes out to the area to be surveyed, walks over it, and checks out the "good" locations for archaeological sites. These likely spots are determined by an untested model or series of models that many archaeologists use in Alaska. These "good" locations are simply high probability zones that have tended to yield sites.

These internal models are based on a set of criteria that the archaeologist employs in the field in order to pick areas to be extensively tested. These criteria, though, are very often based on areas that are most accessible for the archaeologist or simply the most visible. One criteria is the elevated position which commands a view of the surrounding landscape. Sites in these areas were often used as lookouts, they are also the most readily recognized in the field. Another criteria is well-drained ground. Bogs are often avoided because of the difficulty in traversing such areas. Archaeologists tend to stick to drier, more easily covered portions of the survey area. Access to potable water is another criterion. This usually confines archaeologists to present day water systems, and therefore the more recent sites, thus skewing the sample in favor of this kind of site. Finally, the presence of certain kinds of vegetation, such as grass, is usually a very good indicator of site locations. This criterion is also based on the high visibility of these areas in contrast to the surrounding vegetation, and their high correlation with the presence of sites. The above mentioned criteria represent a very biased way of site survey in Alaska. However, archaeologists do locate a great many sites using these axioms. The main problem with this method is its inability to provide useful data for predictive modeling and ultimately for the formulation of general laws with regard to archaeological sites in Alaska. Also, surveying this way eliminates locations that have rarely produced sites, such as wet lands and extremely arid areas. These locations are low probability not because they do not contain sites, but because they have not been looked at and are often dismissed as lacking potential (Clark 1975). In order to obtain the proper data for predictive purposes one must employ a statistically suitable sampling procedure that eliminates investigator bias.

This past summer a sampling technique was employed by the author on two separate archaeological surveys. In both cases the survey area was a strip of land adjacent to a body of water. The first area surveyed, in late May and early June, was the coast of Kulukak Bay located on the northern coast of Bristol Bay. The second area surveyed included the shores of seven lakes in the proposed Lake Clark National Park located approximately 100 miles southwest of Anchorage. It was decided to confine both surveys to the shore areas in order to restrict them to a single ecological zone and thereby making it more likely that sufficient data would be obtained for constructing a predictive model of that ecosystem, given time and manpower constraints.

The major obstacle encountered while surveying in Alaska is the dense vegetation mat that prevents visual access to the ground surface. Simply walking over a place does not mean that one will find evidence of human occupation. Scanning the surface of the vegetation will only reveal a site if there is a subsurface feature whose presence is not obscured by the ground cover, such as a house pit. So, unlike surveys done in the desert west of the "lower 48," walking an area is not sufficient.

To overcome this problem I employed a survey technique which had been discussed at the first and second Annual Conferences on Surveying Woodland Environments. Shovel testing, as it was called, simply amounts to a small hole being dug through the ground cover at regular intervals, within the survey area, thus supplying the archaeologist with the necessary peek at the ground surface.

The shore in each area surveyed was divided into 10km units. This was done to stratify the sample and insure that different portions of the entire survey area would be studied. A random sample of the same area taken as one unit might produce a cluster of sampling points, thereby giving a skewed picture of the site distribution. Stratifying the area by 10km units arbitrarily systematizes the sample, ignoring factors such as topography or vegetative cover that if considered might cause investigator bias in the construction of a stratified sample. Besides, confining the survey to the shore line limits the survey to a single meaningful ecological zone. Smaller divisions based along ecological considerations would not be necessary at this stage since it is these more minute differences that the sampling technique is intended to pick out and use in creating a predictive model.

The width of the survey area was 120m or 1/8 km parallel to the shore so that essentially only the shore would be surveyed. Teams of two people were employed. These individuals 30m apart made two passes over the survey area, one close to the water and one further back. Each surveyor had a 30m wide area to scan in each pass. As a result both surveyors would cover a swath of 60m in each

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pass, therefore covering 120m in two passes.

Each 10km unit was subdivided into 40 ½km subunits. The number 40 is derived from the fact that each 10km unit will be covered twice as is mentioned above. While there are 20 ½km subunits in a 10km unit there would be 40 in a unit twice walked. Twenty ½km subunits would be located close to shore and 20 would be further back. A 10% sample of the 40 subunits was to be intensively sampled using the technique of shovel testing. In each selected subunit a hole was dug every 20m for ½km. The four subunits to be tested were selected by a random number table. In the process of shovel testing a particular subunit, certain problems might arise that would prevent a hole being dug in that place. For example, should a test hole have to be dug in a stream, a pond, or on a bedrock surface the surveyor would pass on to the next hole to be dug, considering their obligation fulfilled for the hole in the untestable location. As a daily goal I set 5km, which amounted to 10km of walking a day given the two passes required to cover the survey area.

In addition to sampling procedures mentioned above, I also employed the intuitive method of site survey. This was to make sure old reliable areas that usually yield sites were checked as well. I did not want to be so restricted that I could conceivably find no sites while being very precise in doing so. After all, these surveys were to locate sites for the purpose of land selection, land management, and compliance with federal law. It is also quite conceivable that a 10% sample of an area would yield nothing. I hoped both techniques together would be a good compromise utilizing the best of both worlds.

You are probably dying to know how this technique worked under actual field conditions. Well, to paraphrase a famous quote 'the best laid plans of mice and archaeologists often go awry'. It did not work or rather it did not work in each instance for a number of reasons. For the Kulukak Bay survey it was just a bit too early in the year and the ground was still frozen. Needless to say, shovel testing is best done in unfrozen soil.

The other survey was a different story. Since Lake Clark was much later in the season, other considerations prevented use of this technique. The primary problem was the amount of time it took to use this procedure. Dense brush made progress difficult and an extremely thick tundra mat, sometimes up to 20cm deep, made the digging of the test holes quite time consuming with up to 20 minutes spent on one hole. Time is a problem but not in an absolute sense. If the technique was time consuming, then that is the way it would have to be. However, we were working under a contract to survey a specified area in a specified time, so in order to live up to our contract, time became a very important consideration. Another problem, although not quite as significant, was locating the preselected subunit with any degree of accuracy. In many cases various geographical features could be used to orient oneself. However, on a nondescript shore line, it becomes a real problem.

Finally, there is a reason less concrete than the others, perhaps, but something to consider nonetheless. It revolves around the psychological aspects of using this technique. All the people involved in the surveys found the technique personally unsatisfying. I feel this is due to the fact that the archaeologists on the surveys had always done this kind of work on an intuitive basis and felt that many areas to be intensively tested were a waste of time. It is also hard to accept the menial, tedious work of shovel testing when one feels efforts could be more productively spent in other areas.

Well, whaddaya going to do? I firmly believe that sampling strategies similar to the one illustrated above are necessary for the development of meaning predictive models about settlement patterns. There is no way around this conclusion in my mind. The solution might lie in divorcing these kinds of sampling procedures from surveys involving set tracts of land that need to be inventoried.

What I see here is a conflict between the wishes of the contracting agency and the necessary procedures for deriving a predictive model in Alaska. The agency usually wants huge tracts of land surveyed in the minimum amount of time with a maximum return in numbers of sites recorded. Their primary interest is in compliance with federal laws directing them to inventory their lands for cultural resources.

One way to solve the problem would be for the agency to allow archaeologists the necessary time to use research designs that lead to predictive models. However, I feel that another approach would be more effective. I suggest that future research designs be confined to more qualitatively oriented problems, such as environmental adaptation or perhaps regional problems in history and prehistory. At the same time I would suggest a program be initiated whose purpose is to develop a predictive model for Alaska. Recognizing the immensity of such a task it could be accomplished on a piece-meal basis with funds being derived from federal agencies charged with the management of cultural resources. The model developed from such a program would be used to explain settlement patterns in circumpolar regions, as well as provide cultural resource managers with an efficient management tool for land under their jurisdiction. In the long run criteria from the tested model could then be employed by archaeologists in their contract surveys of specific regions and thus make for a more complete inventory.

It is my hope that anyone planning to use a rigorous sampling procedure in Alaska, or any other area with similar working conditions, benefit from my experience and be forewarned of the problems as outlined here.

LITERATURE CITED

BACON, G. H. 1971. Archeological survey and excavation near Murphy Lake in the arctic foothills. *In* Final report of the archeological survey and excavations along the Alyeska Pipeline Service Company pipeline route. Department of Anthropology, Fairbanks. (MS)

BORASS, A. S. 1971. Archeological survey results in a transect between Livengood and Fish Creek. *In* Final report of the archeological survey and excavations along the Alyeska Pipeline Service Company pipeline route. Department of Anthropology, Fairbanks. (MS)

CLARK, DONALD. 1975. Archaeological reconnaissance in northern interior district of Mackenzie: 1969, 1970, 1972. Archaeological survey of Canada, paper no. 27. National Museum of Man, Mercury series, Ottawa.

COOK, J. P. 1971. Hogan Hill to Livengood. *In* Final report of the archeological survey and excavation along the Alyeska Pipeline Service Company pipeline route. Department of Anthropology, Fairbanks. (MS)

DE LAGUNA, FREDERICA. 1934. The archaeology of Cook Inlet, Alaska. University of Pennsylvania Press, Philadelphia.

HOLMES, C. E. 1971. The prehistory of the upper

Koyukuk River region in north central Alaska. *In* Final report of the archeological survey and excavations along the Alyeska Pipeline Service Company pipeline route. Department of Anthropology, Fairbanks. (MS)

POWERS, W. R. 1975. 1974 Chukchi-Imuruk archeological survey-final report. Department of Anthropology, Fairbanks. (MS)

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WHAT'S COOKING IN THE CALDERA: MULTIPLE USE ON THE ANIAKCHAK COASTLINE OF ALASKA

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The full version of this report will be made available upon request

CHEMICAL METHODS OF RUINS STABILIZATION

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SITE BC-236

This study area was established on July 31, 1975. The site is precariously located on the banks of Chaco wash and is threatened with eventual collapse due to stream bank erosion. Zoro Bradley conducted a salvage archeology operation at the site in 1958 (1). Parts or all of several walls on the north side of the ruin have collapsed due to stream bank erosion since the 1958 excavation.

Figure 1 shows an outline of the ruin and locates those wall areas where pointing mortar test plots were established. An untreated control mortar and three chemically treated mortars were utilized at this site. The chemicals tested were Union Carbine VMCH Vinylite, Rohm and Haas Rhoplex E-330 and Rohm and Haas Primal 863. Each mortar treatment was placed in four plots yielding exposures facing east, west, north and south in an attempt to ascertain the effects of solar radiation and prevailing wind conditions on treatment life.

The chemicals tested at Site 236 differed in their chemical nature. Union Carbide VMCH Vinylite is a carboxlated vinyl chloride resin purchased as a solid. For this study the resin was dissolved in acetone on a 20% solids basis by volume. The Rohm and Haas Rhoplex E-330 is an acrylic polymer emulsified in an aqueous solution at 47% resin solids by weight. The material was diluted to 10% for this study. Rohm and Haas Primal 863 is an acrylic polymer emulsified in aqueous solution at 35% resin solids. The material is marketed as a leather products treatment. It was diluted to 10% solids for use in this study.

The control treatment was made using only water and soil. The E-330 and 863 mortars were made using soil and the 10% solids solutions of the chemicals. The pointing was done by the traditional methods. The VMCH plots were established by pointing with control mortar and then, after allowing two days drying time, spraying the 20% solids VMCH solution onto the mortar joints.

The site was revisited on July 13, 1976, and observations were made. The control plots were showing signs of erosion, with surface losses of up to 1/2 inch in some joints. At such a loss rate, the area would need repointing in three to four years.

The Primal 863 plots were beginning to erode also, in some places as much as the control plots. The color match was good but the erosional resistance is rather weak.

The VMCH Vinylite plots were showing complete failure. The mortar was very hard and stable and was showing no signs of erosion. The failure was caused by ultraviolet discoloration of the material. The vinyl chloride polymer, which makes up the bulk of the VMCH Vinylite, is not stable under intense ultraviolet radiation from the sun. The discoloration occurs where there is a buildup of a free film of VMCH during application. No discoloration was noted where the VMCH is intimately associated with the soil mortar.

The Rhoplex E-330 plots were showing little or no signs of erosion. The mortar was hard and would not abrade to the touch. The color was stable and closely matched the control mortar. The cracking in the mortar was a result of the presence of bentonite clays in the soil source rather than caused by the E-330.

SITE SJ-1912, LIZARD HOUSE

On October 9, 1975, the study was expanded and plots established at Site SJ-1912, known as Lizard House. This site, like Site Bc-236, is located on the edge of an arroyo and is threatened with eventual collapse due to stream bank erosion. The salvage archeology on the site was performed in 1960 by Maxon (2).

Six new Rohm and Haas chemicals were included in the study at Lizard House, in addition to Rhoplex E-330 and Primal 863. These new products were Primal 826, a water-dispersed acrylic polymer at 35% resin solids, marketed primarily for use in leather finishing; Rhoplex AC-634, a thermoplastic acrylic polymer emulsion at 47% solids, marketed primarily for use as an exterior board coating; Rhoplex AC-61, an acrylic emulsion polymer at 47% solids, primarily marketed as a component of concrete floor paints; Rhoplex SS-521, an acrylic emulsion polymer at 50% solids, marketed primarily as a sprayable exterior clear coating for masonry; experimental Emulsion E-1141, an acrylic emulsion polymer at 37.5% solids, developed primarily for use as an antigraffiti coating; and Acroloid A-21, a low viscosity acrylic ester resin at 30% solids, marketed primarily as a gloss retentive finish for metal surfaces.

The treaments consisted of repointing the joints between the standstone layers with mortar prepared using the chemical solutions at 10% solids in place of water to mix the mud. The soil was obtained from the soil bank at the sanitary landfill in the monument. This soil has been found to have good adhesive properties and only a very small amount of bentonite clay.

Figure 2 is a schematic diagram of the Lizard House Ruin and shows the locations of the treatment plots used in this study. Each treatment consisted of capping the top of the wall and repointing all of the joints in the face of the wall down to ground level. The wall height varied from seven feet in Room 12 down to two feet along the south wall of Room 17.

The site was revisited on July 14, 1976, and some observations were made. The treatments had been in existence for too short a time to draw any major conclusions, but some things were evident. The control mortars were beginning to erode, particularly the west exposure of Room 17. None of the treatments were showing any significant erosion. Most of the chemicals alter the color of the mortar slightly, some greater than others. The Rhoplex E-330 treatments show the

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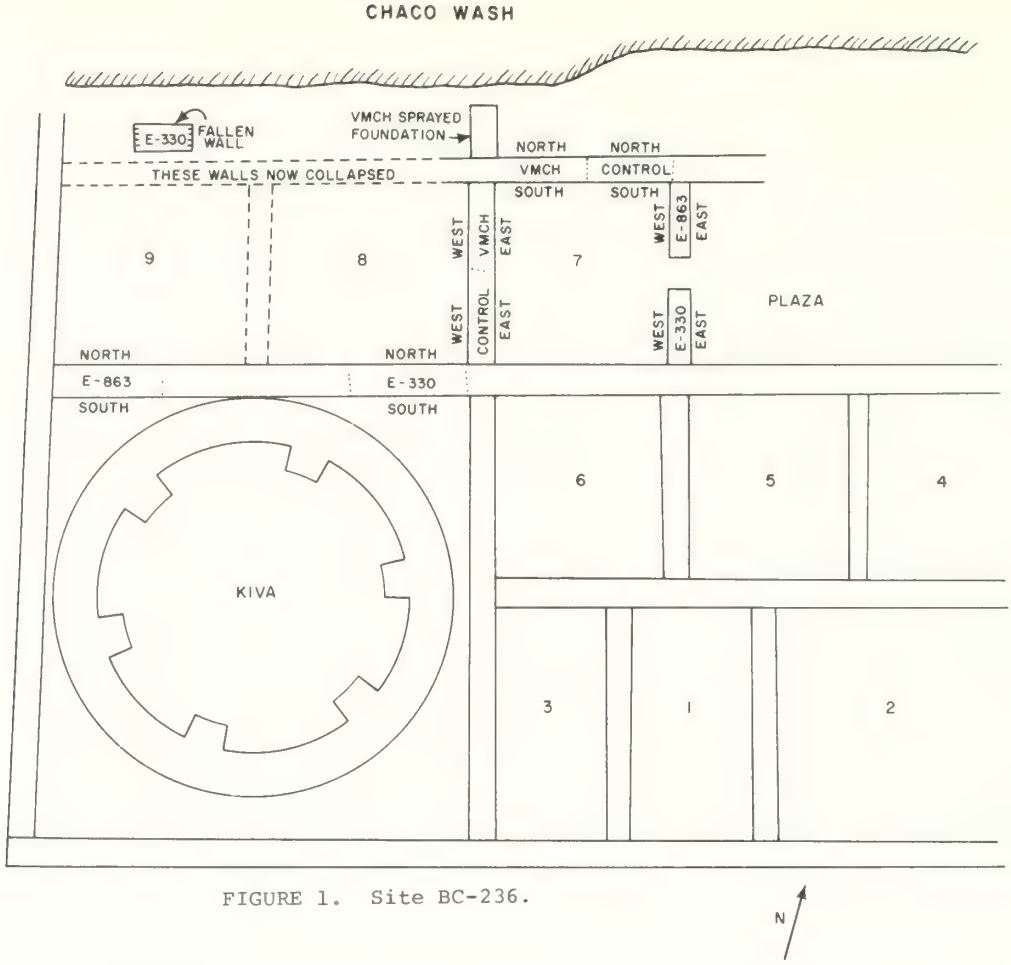

FIGURE 1. Site BC-236.

least amount of brush mark erosion in the capping. This product is performing best thus far at the Bc-236 study area also.

SITE SJ-299

This site is a Basketmaker III pithouse dating from the early A.D. 600s. The site was excavated by Richard Loose of the Chaco Center in the summer of 1973 (Dr. Robert H. Lister, pers. comm.). It is located near the base of Fajada butte looking northwest toward the visitor's center. The pithouse is approximately 6.5 feet deep and 10 feet in diameter. The entire northeastern half of the pithouse wall surface area was used in this study. Figure 3 shows a schematic top view of the pithouse and the assigned treatment plots.

This study was established on October 12, 1975. The purpose of the study is to examine the effectiveness of selected chemical substances as spray-applied coatings for exposed soil walls of excavated pithouses. The chemicals applied to plots at Site SJ-299 were Rohm and Haas Primal 826, Primal 863, Rhoplex E-330, Experimental Emulsion E-1141, Rhoplex AC-61, Rhoplex AC-634, Rhoplex SS-521 and Acroloid A-21. Union Carbide VMCH Vinylite was also applied. The chemical nature of these products has been discussed earlier in this progress report. Each chemical was spray-applied at a concentration of 10% solids. Each chemical was applied to its treatment plot until it began to run off significantly and no more uptake was occurring. Table 1 summarizes the plot size and the volume of uptake of each chemical treatment.

The site was revisited on August 19, 1976, and several observations were made. The spray application of the chemical to the vertical walls of the pithouse did not result in significant penetration into the soil. Only a thin surface coating of less than ¼ inch penetration was achieved. The 10 months of exposure resulted in the treatments cracking and allowing water to get in behind the surface film and spall off significant areas of treated surface. Serious erosion was occurring on most of the treatment plots. None of the chemicals tested was proving to be effective as a soil surface spray in preventing erosion.

This research area will require the development of a method for achieving significant penetration of the preservative into the vertical soil walls in order to provide the necessary degree of erosion protection. Such efforts are presently underway by the authors.

MODERN TEST WALL SITE

The National Bureau of Standards' Center for Building Technology, Materials and Composites Section conducted a comprehensive laboratory study for the National Park Service in 1973 and 1974 (3,4,). They studied more than 95 chemical materials marketed for use as weatherproofing agents. Thirteen of these products performed satisfactorily enough in the laboratory to warrant further study in the field.

These 13 chemicals were Union Carbide RE-280, a silicone emulsion with 40% solids; Union Carbid R-20, an aqueous silicone solution with 20% solids; Hydrozo Clear Special Light, a synthetic gum resin in mineral spirits at 7% solids; Versacryl "E" Clear Sealer #90, a water-thinned acrylic resin at 18.5% solids; Thompson Water Seal, a mixture of polymerized organic and inorganic solids in mineral solvents at 10% solids; Unelko

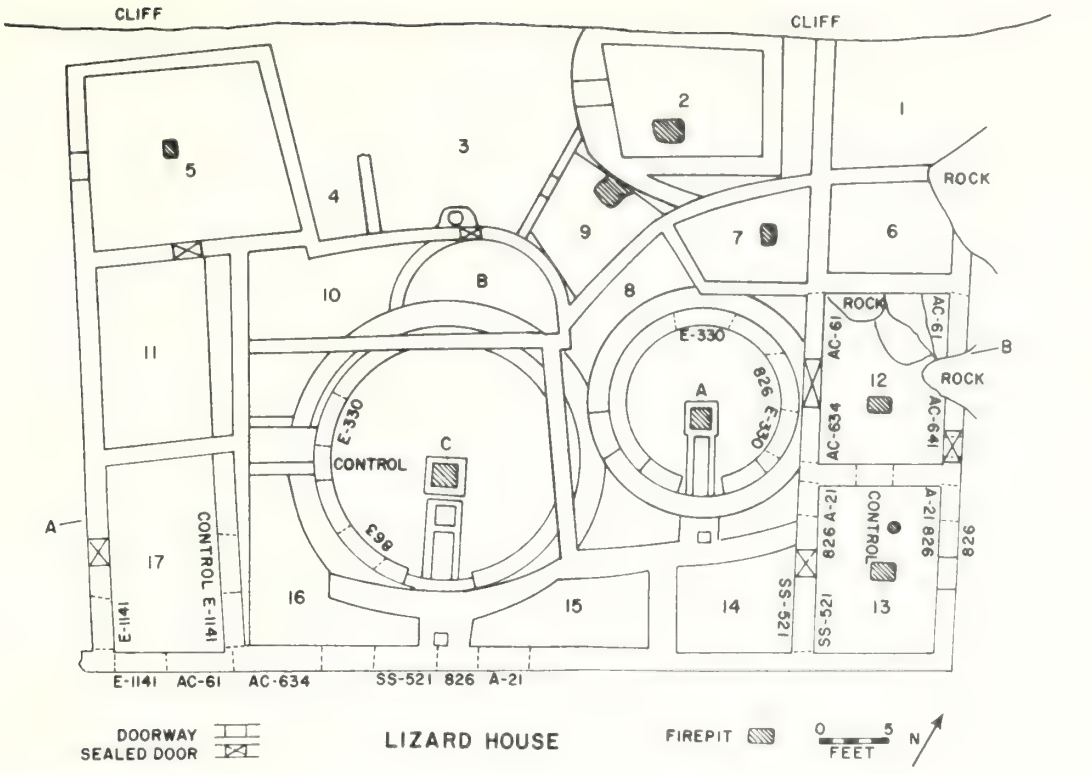

FIGURE 2. Site SJ-1912.

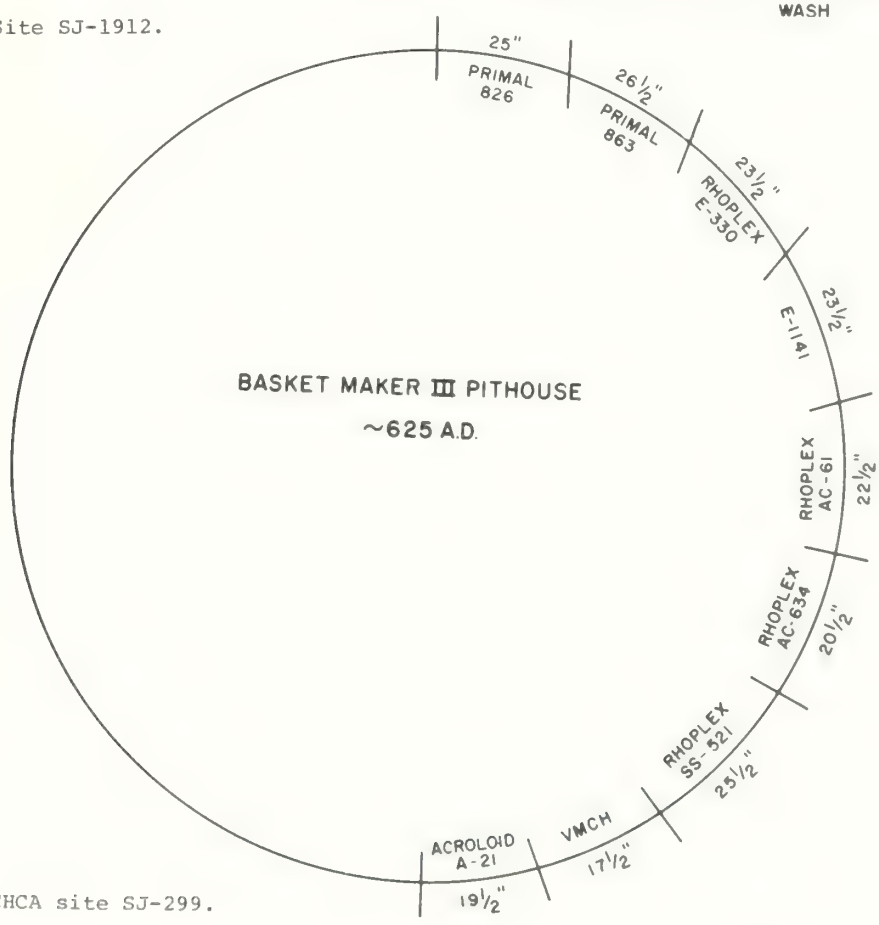

FIGURE 3. CHCA site SJ-299.

TABLE 1. Plot size and volume of chemical uptake, site SJ-299.

Chemical	Height, ft.	Width, in.	Volume applied, Gal.
Primal 826	6.5	25.0	6.5
Primal 863	6.5	26.5	3.0
E-330	6.5	23.5	2.5
E-1141	6.5	23.5	4.0
AC-61	6.5	22.5	2.0
AC-634	6.5	20.5	3.0
SS-521	6.5	25.5	4.0
VMCH	6.5	17.5	3.5[a]
A-21	6.5	19.5	5.0

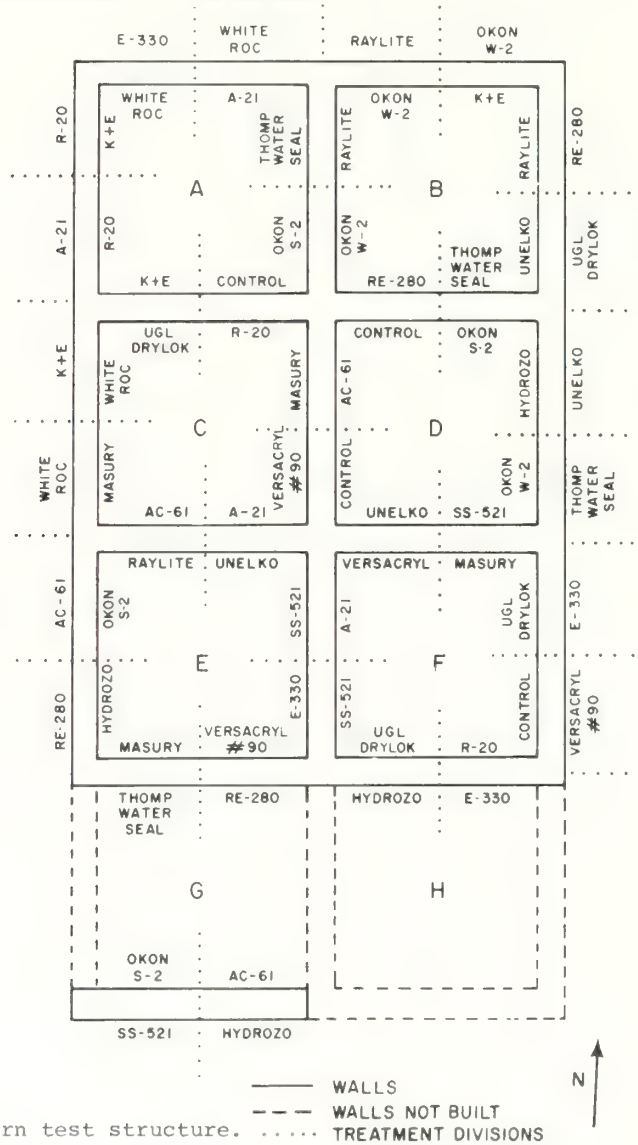

FIGURE 4. Modern test structure.

Water Repellent, a modified silicone blend in organic solvents at 10% solids; Okon S-2 Waterproofing, a hydrocarbon solvent solution of several waterproofing materials at 10% solids, Okon, W-2 Waterproofing, an aqueous emulsion of film forming resins at 10% solids; Raylite D-36, a mixture of butyrate resins in mineral spirits solvent at 36% solids; K & E Penetrating Mineral Sealer, a water-based solution of mineral salts at 30% solids; White Roc 8, a blend of polymeric silicone resins in xylene solvent at 10% solids; Masury Wendex Silicone Clear Water Repellent, a silicone resin in xylene solvent at 5% solids; and United Gilsonite Laboratories Drylok Silicone, a silicone resin in mineral spirits solvent at 5% solids.

In addition to the 13 chemicals selected from the National Bureau of Standards' work, four Rohm and Haas products used in the field studies described earlier in this report were included in the phase of the research. These products were, Rhoplex E-330, Rhoplex SS-521, Rhoplex AC-61 and Acroloid A-21. This brought the total to 17 chemicals to be included in the expanded testing program at Chaco Canyon.

It was felt that the limited availability of prehistoric wall area for use in stabilization testing and the variability in directional exposure and plot size under prehistoric structure conditions made it advisable to construct a modern stone edifice for use in testing the 17

selected chemicals. In consultation with monument personnel, it was decided that a suitable location for the test structure was near the sewage lift station, 200 yards east of the visitors' center.

The test wall will be used to study two factors simultaneously. First, the stone in each plot was sprayed with the chemical assigned to that plot and secondly, the joints between the stone layers were pointed with mud mortar prepared with the chemical solution for that plot. The foundation soil beneath each plot will have water applied to it on a regular periodic basis in an effort to promote the capillary rise of moisture up into the stone wall. This process will accelerate the weathering potential of the stone and provide a good test of each chemical's effectiveness in resisting stone decay. This should also provide a good test of each chemical's potential as a repointing mortar additive.

Figure 4 shows a schematic outline of the test structure built and the chemical product assigned to each plot. The test plots are 4' long and 3½' high. An average of 11 layers of Cliff House sandstone (5,6) were used to construct each wall. The chemical products were assigned to each plot by a random-draw procedure and each treatment should have a plot facing east, west, north and south. An error in assignment, however, resulted in Hydrozo having two south exposures and no north exposure and AC-61 having two north exposures and no south exposure.

The chemicals were first sprayed on the test walls and allowed to dry, and then the joints were pointed with the treated mortar. These operations were performed on July 20 and 21, 1976. Several observations were made at the time of treating the plots. First, the organic solvent based materials all were absorbed by the stone at a faster rate than most of the aqueous-based materials. The one exception to this was the water solvent K & E Penetrating Mineral Sealer, which was absorbed by the stone at the fastest rate of all the 17 chemicals tested. Secondly, most of the chemicals caused a slight darkening of the stone. This effect was most noticeable when an untreated control plot was adjacent. The effect was indistinguishable when all the wall had been treated with chemical. The most serious discoloration occurred with Rhoplex SS-521 and Acroloid A-21. Both of these chemicals, rather than darkening the stone, formed a chalky-white surface on the stone that was still present two days after treatment. Thirdly, the organic solvent materials failed as mortar additives. The mortar was hard to work with because of a lack of adhesive properties and when it dried it left behind a loose-grained powder rather than a hard, binding mortar. This effect is due to the fact that the organic solvent flocculates the clay mineral fraction of the soil and the interaction between the sand particles and the clay is interferred with. This prevents the formation of a uniform bonded mortar upon drying. This study will now be monitored over the coming months for treatment effectiveness. Other promising chemical products may be added to the study and the unbuilt walls of Rooms G and H completed to make room for the expansion.

REFERENCES CITED

1. BRADLEY, A. A. 1959. Site BC-236, Chaco Canyon, Ms. for National Park Service, Globe, Arizona. 93 pp.
2. MAXON, J. D. 1963. Lizard House, A Report of a Salvage Archeological Excavation at Chaco Canyon National Monument, New Mexico in 1960. Ms. for National Park Service, Globe, Arizona. 40 pp.
3. CLARK, E. J., CAMPBELL, P. G. and FROHNSDORFF, G. 1975. Waterproofing Materials for Masonry. NBS Technical Note 883. National Bureau of Standards, Washington, D.C. 78 pp.
4. SLEATER, G. A., CLIFTON, J. R., and FROHNSDORFF, G. 1976. Preliminary Criteria for the Selection of Preservatives for Natural Building Stone. National Bureau of Standards. Washington, D.C. 19 pp.
5. BYRON, K. 1954. The Geology of Chaco Canyon, New Mexico in Relation to the Life and Remains of the Prehistoric Peoples of Pueblo Bonito. Smithsonian Miscellaneous Collections, Volume 122, Number 7. Washington, D.C. 65 pp.
6. VIVIAN, G., and MATHEWS, T. W. 1964. Kin Kletso, a Pueblo III Community in Chaco Canyon, New Mexico, Southwest Parks and Monuments Association, Technical Series, Volume 6. Globe, Arizona. 214 pp.

PRESERVATION OF ROCK ART

Christy G. Turner II, Richard L. Bradshaw and William J. Burke[1]

INTRODUCTION

Rock art has long been recognized as an important source of information regarding prehistoric cultures in many regions scattered throughout the world. The persistent slow natural deterioration of these irreplaceable artifacts has been greatly accelerated in recent times by vandalism, air pollution and the forces of civilization generally (Smits 1968).

In view of this situation, it is not surprising that the preservation of rock art has attracted growing interest, particularly during the past decade (Leroi-Gourlan 1967; Pager 1971; Woodhouse 1971). Concern for conservation and protection of antiquities has also resulted in a greater research effort on the related challenge of preserving major stone monuments and structure of significant historical interest (Price 1975).

Greater numbers and more styles of prehistoric rock art are found in the Southwestern United States than elsewhere in North America (Mallery 1886; Stewart 1929, 1936; Cain 1950; Heizer and Baumhoff 1962; Turner 1963, 1971; Kirkland and Newcomb 1967; Schaafsma 1962). Thousands of examples of pictographs and petroglyphs occur within the Glen Canyon system. These range in age from modern examples left only a few years ago, through a series of four evolutionary styles more than 4,000 to 8,000 years old (Turner 1971). The majority of the Glen Canyon designs are petroglyphs, that is, designs which have been pecked or abraided onto a rock surface. Far fewer are painted designs or pictographs, usually of white mineral pigment, but occasionally in or including other colors. Pictographs, because of their delicate nature are rare and poorly preserved. The few known examples occur chiefly on dry rock alcove walls, or beneath overhanging rock ledges. Their rarity makes them valuable for both scientific and humanistic considerations.

An outstanding feature of the 11-13th century Kayenta Anasazi campsite (42Ka235) in Davis Gulch on Lake Powell is a forty-foot panel of about 20 pictographs. This panel of anthropomorphic and geomorphic paintings is among the largest and best preserved collection of pictographs in the Southwest. Its potential destruction by the threat of an increased water level prompted efforts to find a suitable means of preserving this panel in the event that it would be inundated.

A major objective of this research was to undertake exploratory studies designed to uncover promising leads to treatments which would permit the effective preservation of prehistoric rock art in a practical manner with little or no change in outward appearance.

In a comprehensive summary of the preservation of natural stone which included more than 300 references covering the period 1839-1965, Lewin (1966) noted that "despite more than a century of experimentation and field testing, the problem of inhibiting, arresting or preventing the deterioration of natural stone remains largely unresolved." A more recent review by Price (1975) leads to a similar conclusion.

Many types of polymeric materials have been proposed for the preservation of natural stone (Lewin 1966; Sleater 1974). The relatively large size of polymer molecules, however, greatly limits the rate and depth of penetration so that any protection gained is largely limited to a thin surface layer. The formation of a polymer by the polymerization of low molecular weight monomers within the stone structure was reported by Munnikendam (1967, 1973) as a possible means of obtaining the desired degree of penetration essential for improvement in the structural integrity of the rock.

DISCUSSION

The present research was primarily directed toward a study of the *in situ* polymerization of methyl methacrylate as a potential means of achieving substantial improvement in the compressive strength and water resistance of representative types of sandstone found in areas of the Southwest having significant examples of rock art.

Poly(methyl methacrylate), known commercially as Lucite (Du Pont) or Plexiglas (Rohm and Haas), is characterized by its outstanding resistance to sunlight and outdoor exposure, high tensile strength, outstanding transparency, and excellent adhesion to silica and other inorganic materials. These properties along with commercial availability, relatively low cost and ease of polymerization made methyl methacrylate an attractive candidate for initial studies.

The free radical-initiated polymerization of methyl methacrylate has been extensively studied over the past forty years and shown to consist of several steps including initiation, propagation, and termination (Burke 1962).

Free radicals are readily generated by the decomposition of compounds such as peroxides and azo compounds. Once the polymerization is started by reaction of a free radical with an active vinyl monomer such as methyl methacrylate, the propagation reaction is exothermic and can proceed very rapidly to yield an extremely high molecular weight structure. The major termination reactions in the free radical initiated polymerization of methyl methacrylate involve coupling or disproportionation, with the latter predominating. Steps in the polymerization of methyl methacrylate by a free radical mechanism are shown below, where $R^{\cdot}$ is a free radical and where n can have values well in excess of 1,000.

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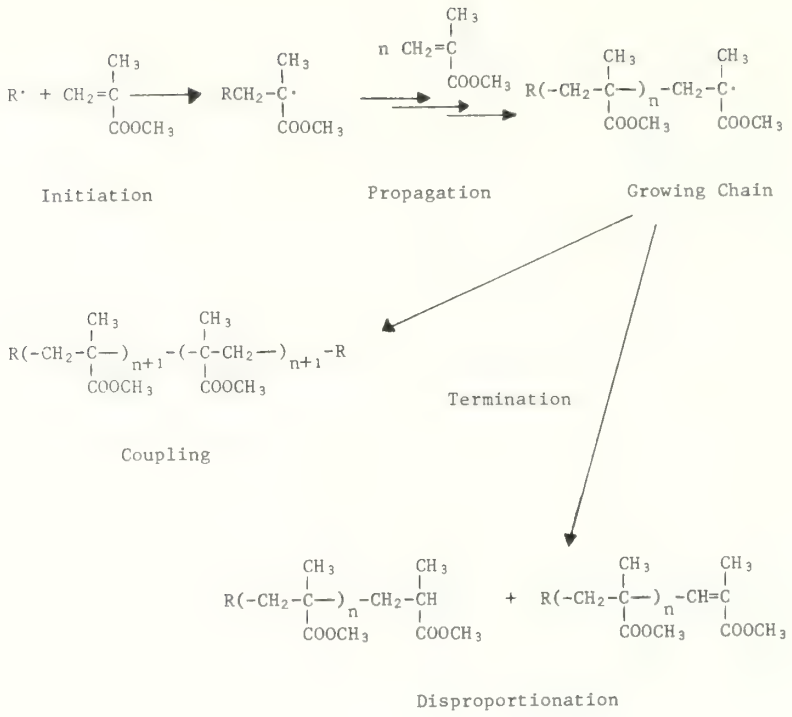

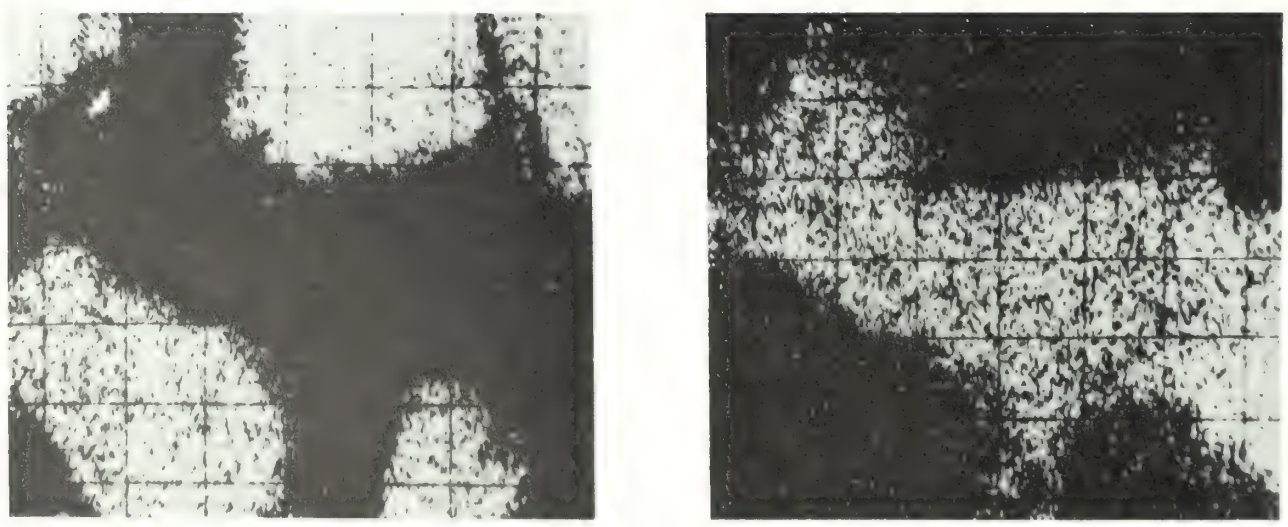

FIGURE 1. Electron microprobe X-ray emission images of a polished cross-section of Navajo sandstone treated with methyl methacrylate containing 2% ethylene glycol dimethacrylate and 1% benzoyl peroxide by partial immers procedure.

Complete immersion of a stone specimen in the monomer solution provides a convenient method for keeping void spaces filled during polymerization but this procedure has inherent practical limitations. Application of the treating solution as a pressurized spray while convenient for field use has the disadvantage of substantial monomer loss through evaporation. The resultant cooling of the treating solution along with the air introduced results in an undesirable reduction in the rate of polymerization.

An alternate possibility involves placing a rock sample in a shallow layer of treating solution in a loosely sealed vessel. This partial immersion method has the advantage of permitting substantial *in situ* polymerization in a convenient reproducible manner with a relatively small volume of treating solution required to saturate the void spaces in the stone with monomer through capillary action. Accordingly, this procedure was utilized as a convenient laboratory method for studying the importance of major reaction variables in the *in situ* polymerization of methyl methacrylate.

A series of Navajo sandstone specimens were treated with methyl methacrylate solutions containing 1% benzoyl peroxide by the partial immersion procedure at a temperature of 30-32^{o} for a period of about two days. The samples were then removed from the treating bath and allowed to cure at room temperature. The compressive strength of the treated sandstone (6,600 psi) was well over five times that of the control (1200 psi). The weight gain of the treated samples was in the range of 5 to 6%. Complete filling of the void spaces with polymer would require a weight gain in the range of 7 to 8%.

Incorporation of 2% ethylene glycol dimethacrylate based on the methyl methacrylate in the treating solution provided a further marked improvement in compressive strength (10,800 psi). The dimethacrylate functions as a crosslinking agent in that it has the capability of tying together growing polymer chains to form a three dimensional network. This results in a more rigid polymer structure and greatly speeds up the rate at which the polymer grows in size. An increase from 2 to 5% of the crosslinker, however, resulted in a decrease in compressive strength (9,900 psi). With 10% of dimethacrylate the compressive strength dropped to a value (5,000 psi) lower than that obtained with methyl methacrylate alone. The resistence of the sandstone to immersion in water was greatly increased by *in situ* polymerization of methyl methacrylate both with and without a crosslinking agent.

The use of 10% toluene as a solvent resulted in cores having compressive strengths substantially below those obtained under comparable conditions in the absence of a solvent. Polyvinyl acetate is well known for its excellent adhesive properties. Addition of four to ten percent of vinyl acetate to methacrylate treating solutions, however, resulted in treated specimens showing substantially lower compressive strengths than were obtained with methyl methacrylate alone.

Since the rate of free radical polymerization is a function of initiator concentration, increasing the concentration of benzoyl peroxide in the methyl methacrylate treating bath offers a convenient means of speeding up the polymerization at a given temperature. It was found, however, that with 2% benzoyl peroxide surface cracking was quite evident after 45 hours and pronounced after 51 hours. The surface cracking was considerably more severe when the concentration of benzoyl peroxide was 5%.

An interesting feature of a cross section of specimens treated by the partial immersion procedure was the presence of three distinct zones. The major portion of the treated rock was a hard, dense inner core which was separated from the surface zone by a thin boundary layer. Examination with a scanning electron microscope indicated that the thin boundary layer was composed of dense polymer, the formation of which resulted in the dislocation of grains in the sandstone matrix. In contrast to the hard inner core which appeared to be substantially filled with polymer, the outside layer was found to be much more porous.

While the present data do not permit a complete explanation of the formation of the three distinct zones, it appears that this phenomena may be related to the dynamic equilibrium between liquid and gaseous phases at the rock surface in the partial immersion process. Evaporation of monomer from the surface layer could be expected to favor a more porous structure and the resulting cooling would slow down the rate of polymerization near the surface. Condensation of monomer at the boundary layer would then favor the build-up of a dense polymer layer in this region which in time could cause disruption of the sand grains in the surface region and subsequent cracking. It is important to note that zone formation was not observed in sandstone treated by either the complete immersion or the wet spray procedure, neither of which involve the presence of an equilibrium condition between the gaseous and liquid phases of methyl methacrylate at the surface layer.

Incorporation of methyl methacrylate in the sandstone by a wet spray process offers certain potential advantages including ease of application, relatively low loss of monomer by evaporation and very little aeration of the monomer during application. At room temperature, however, this method required repeated application of methyl methacrylate treating solutions over a period of several days to obtain an increase in weight of even 0.5%. Use of N,N-dimethyl-p-toluidine as an activator for the benzoyl peroxide initiator (Munnikendam 1967) increased the rate of polymerization somewhat but was accompanied by discoloration of the treating solution.

A significant improvement was obtained, however, through use of methyl methacrylate treating solutions heated to 60^{o}C for about 15 minutes prior to application. In this manner five applications of methyl methacrylate containing 1% ethylene glycol dimethacrylate and 1% benzoyl peroxide over a 75-minute interval resulted in a weight gain of 1.7% after curing at 35^{o}C. Although there was a readily detectable increase in cohesive strength and water resistance, the improvement was considerably less than that obtained by the partial immersion process.

The use of hot treating solutions has serious inherent disadvantages particularly in field applications. As an alternate approach to a more practical wet spray treatment the use of Vazo 33W as the polymerization initiator was studied. This product, 2,2'-azobis (2,4-dimethyl-4-methoxyvaleronitrile), recently available on an experimental basis from the Du Pont Company, is a usually active source of free radicals at room temperature. At 25^{o}C a single wet spray application of methyl methacrylate containing 1% of Vazo 33W resulted in an increase in weight of 0.5% after curing for several days at room temperature. Four applications of methyl methacrylate containing 2% ethylene glycol dimethacrylate and 1% Vazo 33W resulted in a weight gain of 2% after curing. Even with only 0.5% polymer introduced in this

manner, the comprehensive strength of the resulting sandstone was almost twice that of the control. As in the partial immersion treatments, use of 2 to 6% of ethylene glycol dimethacrylate resulted in a significantly higher compressive strength and greatly improved water resistance.

In order to learn more about the nature and location of the polymer formed in the sandstone, representative treated and untreated specimens were subjected to microscopic examination. While high power optical microscopes even with polarized light were of limited utility, results obtained with a scanning electron microscope in combination with an electron microprobe provided highly informative visual records of polymer formation within the rock matrix.

Figure 1 shows the characteristic silicon and carbon x-ray images of a cross-section of the inner core of a specimen treated by the partial immersion process to obtain a 6% gain in weight. The light regions on the left figure represent high x-ray emission produced by silicon and accordingly defines the sand grain boundaries. The carbon x-ray image of the same area of the sample, shown in the light section of the right figure, establishes the location of the dense polymer formation between the sand grains. The fact that the light sections of the two figures complement each other clearly establishes the rather extensive filling of the voids in the sandstone with polymer and the close contact of the polymer with the silica grain surfaces.

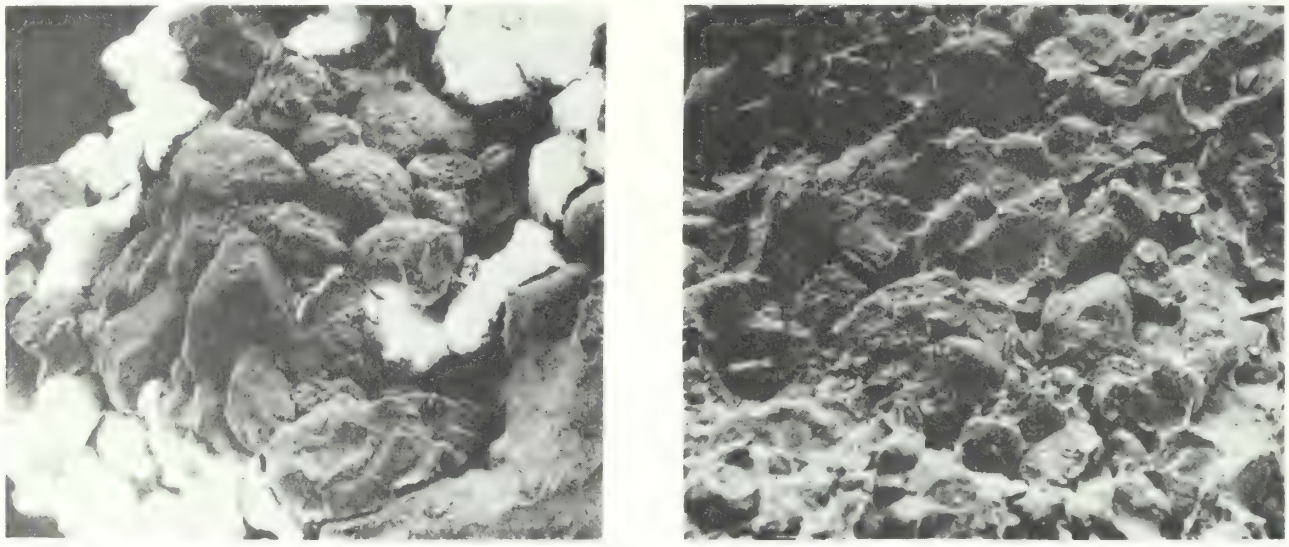

FIGURE 2. Scanning electron microscope images of Navajo sandstone at 100 X. The specimen on the right was treated with methyl methacrylate containing 2% ethylene glycol dimethacrylate and 1% benzoyl peroxide by the partial immersion procedure.

In the scanning electron microscope pictures in Figure 2, the polymer film covering the partial immersion treated sandstone grains is clearly visible at a magnification of 100x. The weight gain was 6%. A gold coating about 200°A thick was applied to the samples to improve image resolution in the scanning electron microscope. The light areas in the untreated sample are a result of loss of gold-coated grains from the poorly cemented rock matrix during sample preparation.

Figure 3 shows the same treated sandstone at higher magnification. The continuous nature of the polymer film between the grains is clearly observable. The coating on the grain in the center of the field of view was apparently removed during cleavage of the sandstone for sample preparation. The image on the right at a magnification of 1200x gives an indication of film thickness.

Scanning electron microscope studies were also carried out on Navajo sandstone treated with a methyl methacrylate solution containing 2% ethylene glycol dimethacrylate and 1% Vazo 33W to effect a 2% weight gain. While the extent of polymer deposition was considerably less than that observed with the partial immersion treated sample in Figure 3, the covering of individual grains with a thin polymer film is readily seen with the scanning electron microscope as well as void spaces between the sand grains.

SUMMARY

These preliminary studies indicate that the *in situ* polymerization of methyl methacrylate in sandstone offers an attractive potential approach to the preservation of both pictograph and petroglyphs by greatly increasing the cohesive strength and water resistance of sandstone. Further research is needed to develop a practical method of obtaining the desired degree of *in situ* polymer formation in the sandstone matrix in the field. Wet spray application of methyl methacrylate treating solutions containing ethylene glycol dimethacrylate as a crosslinking agent and Vazo 33W as a polymerization initiator appears to offer an attractive approach toward achieving this objective.

EXPERIMENTAL

Materials. Navajo Sandstone used in this research was obtained from the Davis Gulch area on Lake Powell. Monomers studied included: commercial grade methyl methacrylate inhibited with 10 ppm of *p* methoxyphenol (Rohm and Haas); ethylene glycol dimethacrylate inhibited with 60 ppm of hydroquinone (Ware Chemical, Inc.) and practical grade vinyl acetate inhibited with hydroquinone (Eastman). Reagent grade benzoyl peroxide (Baker) and 2,2-azobis (2,4-dimethyl-4-methoxyvaleronitrile), available from Du Pont under the trade name of Vazo 33W, were employed as polymerization initiators.

Partial Immersion Treatment. A 384.4 g Navajo sandstone specimen was placed in a 250 ml beaker containing 100 ml of methyl methacrylate, 2 ml of ethylene glycol dimethacrylate and 1.0 g of

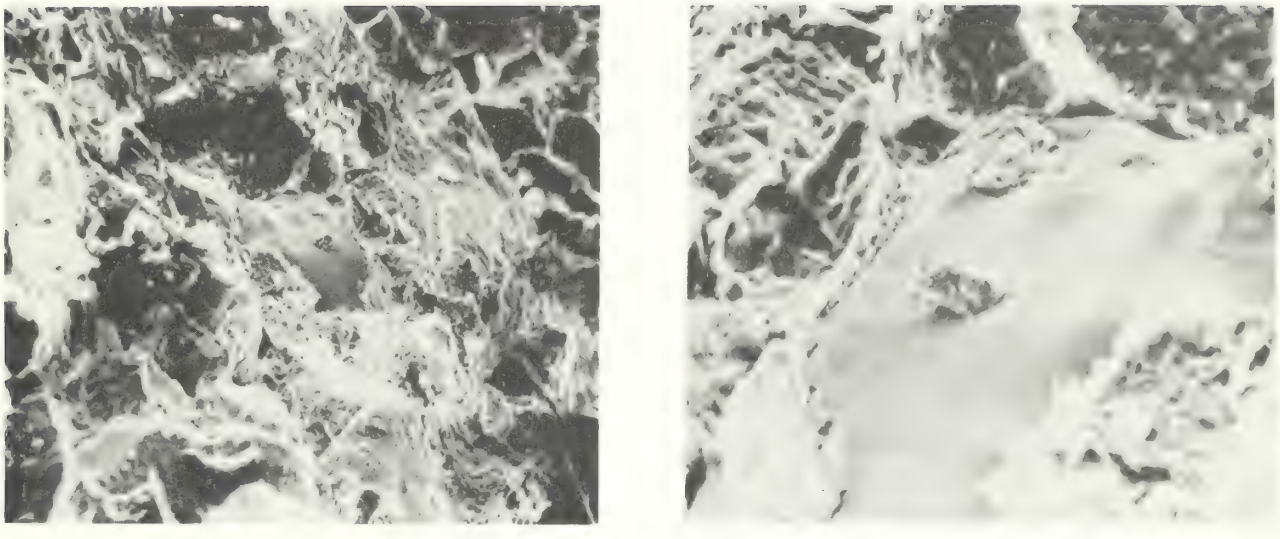

FIGURE 3. Scanning electron microscope images of Navajo sandstone treated with methyl methacrylate containing 2% ethylene glycol dimethacrylate and 1% benzoyl peroxide by partial immersion procedure.

benzoyl peroxide. The beaker was sealed loosely with aluminum foil and kept for two days at 30-32°C. The sample was removed from the beaker and cured at room temperature for four days, after which time no further loss in weight was observed. The treated sample weighed 405.4 g, an increase of 5.6%, and had a compressive strength of 10,800 psi. A cross section of the sample showed the presence of three distinct zones: a hard, dense inner core separated from the outer zone (1-5 mm thick) by a thin boundary layer (0.001 to 0.05 mm thick). The inner core comprised the major portion of the sample and was darker in color than the outer layer.

Wet Spray Treatments. A. With Vazo 33W as Initiator. A solution of 25 ml of methyl methacrylate, 0.5 ml of ethylene glycol dimethacrylate and 0.5 g of Vazo 33W was kept at 30°C until the viscosity was four times that of the original solution. The solution was then applied rapidly in a thin streak (wet spray) to a sample of Navajo sandstone weighing 411.1 g. This process was repeated four times at intervals of 10-15 minutes. After curing at room temperature for two days, when no further loss in weight was noted, the sample weighed 419.6 g., a gain in weight of 2.3%. The compressive strength was 2500 psi.

B. With Benzoyl Peroxide as Initiator. A solution of 100 ml of methyl methacrylate containing 1.0 ml of ethylene glycol dimethacrylate and 1.0 g of benzoyl peroxide was warmed to 60°C and kept at that temperature for 15 minutes before being applied as a wet spray to a Navajo sandstone fragment weighing 1475.7 g. The process was repeated four times over a two-hour interval. After curing for four days at room temperature, the rock reached a constant weight of 1501.0 g (1.7% increase). A cross section of the rock showed no appreciable change in color and no zone formation. The compressive strength of the sample was 1800 psi.

Application of unheated methacrylate treating solutions comparable to the above at room temperature resulted in a gain in weight of less than 0.5% even after as many as 20 applications of the treating solution over a period of several days.

Equipment. An Advanced Materials Research Model 1000-A scanning electron microscope and a CAMECA Model MS-46 electron microprobe were used to study the structure of treated and untreated sandstone specimens. Compressive strength measurements were made on a Reihle Model KA-120 and Tinius Olsen Super L equipment. The values given are the average for at least three determinations on orthorhombic specimens taken from the inner core of the rock specimen.

ACKNOWLEDGMENT

We would like to express appreciation to the Bureau of Land Management and the Bureau of Reclamation for the support of this work which was coordinated by the Midwest Archeological Center of the National Park Service. We also wish to thank Dr. F. A. Calabrese, Mr. Roberto Costales and Mr. Edward Holsworth for helpful discussions regarding the research and Miss Sharon Kauffman for technical assistance.

LITERATURE CITED

BURKE, W. J. 1962. Polymerization. Encyclopedic Dictionary of Physics, Pergamon Press. 5:584-587.

CAIN, H. T. 1950. Petroglyphs of Central Washington. University of Washington Press. Seattle.

HEIZER, R. F. and M. A. BAUMHOFF 1962. Prehistoric rock art of Nevada and Eastern California. University of California Press. Berkeley.

KIRKLAND, F. and W. W. NEWCOMB, JR. 1967. The Rock Art of Texas Indians. University of Texas Press. Austin.

LEROI-GOURHAN, A. 1967. Treasures of Prehistoric Art. H. N. Abrams, Inc. New York, N. Y.

LEWIN, S. Z. 1966. The preservation of natural stone, 1839-1965: An annotated bibliography. Art and Archeological Technical Abstracts. 6(1)185-273.

MALLERY, G. 1886. Pictographs of the North American Indians. 4th Annual Report of Bureau of American Ethnology. Washington, D. C.

MUNNIKENDAM, R. A. 1967. Preliminary notes on the consolidation of porous building materials by impregnation with monomers. Studies in Conservation. 12:158-161.

_____. 1973. A new system for the consolidation of fragile stone. Studies in Conservation. 18:95-97.

PAGER, H. 1971. Ndedema. Akademische Druck-u. Verlagoanstalt Graz, Austria. 375 pages.

PILLES, PETER J. 1974. Petroglyphs of the Little Colorado River Valley, Arizona.

PRICE, C. A. 1975. Stone decay and preservation. Chemistry in Britain. XI:350-353.

RITTER, DALE W. and ERIC W. RITTER 1973. Prehistoric pictography in North America of medical significance. IXth I.C.A.E.S. Chicago. Xerox. 112 pp.

SCHAAFSMA, POLLY 1962. Rock art of the Navajo Reservoir. El Palacio, Vol. 69, No. 4. Santa Fe.

SLEATER, G. A. 1973. A review of the subject of natural stone preservation. National Bureau of Standards. IR74-444. 32 pp.

SMITS, L. G. A. 1968. Some proposals concerning the preservation of rock painting in Lesotho. Lesotho Notes and Records. 7:36-48.

STEWARD, J. H. 1929. Petroglyphs of California and adjoining states. University of California publications in American Archaeology and Ethnology. Vol. 24, No. 2. Berkeley.

_____. 1936. Petroglyphs of the United States. Annual Report of the Smithsonian Institution. Washington, D. C.

TURNER, C. G. II. 1963. Petrographs of the Glen Canyon region. Museum of Northern Arizona. Bull. 38.

_____. 1971. Revised dating for early rock art of the Glen Canyon region. American Antiquity, Vol. 36, No. 4. October, 1971.

WOODHOUSE, H. D. 1971. Archeology in Southern Africa. Purnell: Capetown.

MAGNETIC SURVEYING OF ARCHAEOLOGICAL SITES

John E. Weymouth[1]

INTRODUCTION

Among the various methods used to evaluate an archaeological site prior to excavation, one of the most useful has been that of magnetic surveying. This tool was borrowed from geophysicists and adapted to archaeological problems by the group under Aitkin at Oxford in the late 1950's (Aitkin 1974). Since then groups in England, Germany (I. Scollar) and Italy (R. Linington) have used it extensively. E. Ralph and B. Beven (Beven 1975) at the University of Pennsylvania have used the method on sites in the Old World and one or two sites in this country. In addition Black and Johnston (1972), Breiner and Cole (1972), and Arnold and Kegley (1973) have conducted surveys in this hemisphere. In the last two or three years, there has been an increased interest in the method with several exploratory studies reported at archaeological meetings.

We at the University of Nebraska and the Midwest Archaeological Center have been conducting surveys on a variety of Central Plains sites since 1972. In this paper I will describe briefly the theory of the method and discuss two examples--the Ward and Guerrier Trading Post at Fort Laramie and the Knife River Indian Villages Historical Site.

THEORY OF MAGNETIC SURVEYING

The earth's magnetic field, when viewed on a local scale, can be visualized by a uniform-distribution of lines pointing northward and dipping into the earth in the northern hemisphere. At Nebraskan latitudes the angle of dip below the horizontal is 70°. Any object in the earth's magnetic field such as soil, rocks or bricks can become magnetized. That is, the constituent atomic magnetis of the object line up in the external magnetic field. This can come about by one of two processes. 1) Soils containing iron oxides can acquire a permanent or "thermoremanent magnetization" by being heated to several hundred degrees centigrade then cooled in the earth's field. 2) Even without being heated, soils with iron oxides can become slightly magnetized due to the external magnetic field. This "induced magnetization" is proportional to the strength of the external field as well as a property of the substance known as its "magnetic susceptibility." This latter can vary over several orders of magnitude depending, among other things, on the amount of iron oxide in the soil and on its crystallographic form. Thus average top soil may have a susceptibility ten times that of limestone or granite gravel, while humic soil may have a susceptibility ten times or greater, than that of average top soil. For further information see Aitkin (1974) or Tite (1972).

If a subsurface feature has a sufficient magnetization or magnetic "susceptibility contrast" compared to its surrounding soil, it acts like a local magnetic dipole, setting up its own magnetic field. A measurement of the total field in the neighborhood of such a feature will then yield the sum of the external (uniform) field and the local (dipole) field. This resultant field displays an anomaly near the feature, as diagrammed in Figure 1.

Several properties of the magnetic anomaly produced by an isolated feature should be noted.

1. The maximum of the anomaly lies to the south of the feature, a distance equal to about one-third of the depth of the feature (distance from measurement to feature).

2. The width of the anomaly at half maximum is about equal to the depth of the feature.

3. The size of the anomaly (strength of the maximum) drops off as the inverse cube of the depth of the feature.

4. If the feature has a lower magnetic susceptibility than the surrounding soil, the anomaly will have the same shape but will be negative.

Typical features that have a measurable positive magnetic contrast with respect to their surroundings are fire hearths and pits or ditches filled with humic soil surrounded by low humic soil. Structures made of rocks with low iron content surrounded by average soil would have a negative magnetic contrast.

One more aspect of the earth's magnetic field must be considered, the so-called "diurnal variation." Because of ionic currents in the atmosphere the earth's magnetic field is not constant in time. A typical time variation is given in Figure 2. The general trend is a diurnal variation, dropping down during the middle of the day. Superimposed on this are short time fluctuations whose severity may be sizeable during periods of "magnetic storms."

SURVEY METHODS

The most suitable instrument for measuring the magnetic field is the proton magnetometer. There are less sensitive magnetometers that are cheaper, and there are more sensitive instruments which are very costly, but the proton magnetometer is, in most cases, the best compromise. The magnetometer measures the total magnetic field at the position of the sensor to one gamma (the earth's field in Nebraska is roughly 57000 gamma). The main drawback of the proton magnetometer is that it is not a continuous reading instrument but must be cycled through a four second polarization and readout sequence.

The purpose of a survey is to locate measurable anomalies with a minimum of time. Single traverses are rapid but are only successful if they pass over features whose locations are roughly known or over extended linear features. Thus a survey over a grid of points is usually required. A good compromise grid unit is 1 meter or 2 feet. A smaller grid unit will yield more detail but the time for collecting data quadruples when the grid unit is cut in half.

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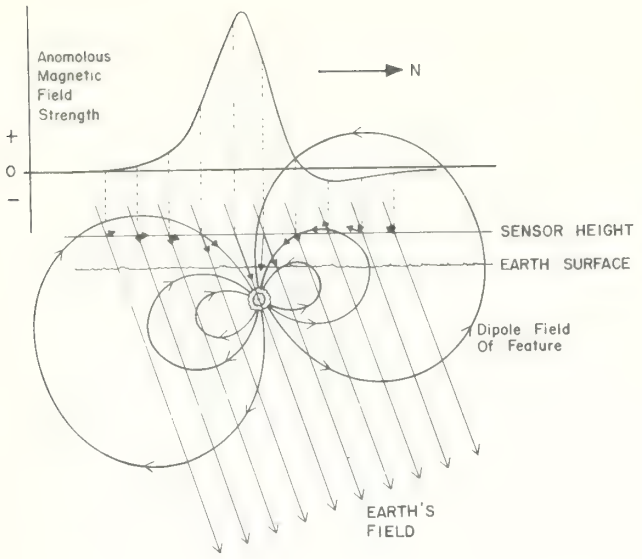


FIGURE 1. Magnetic anomaly produced by an isolated, subsurface feature. The anomalous field strength is that which could be measured in a south to north traverse where the magnetic inclination is 70 degrees.

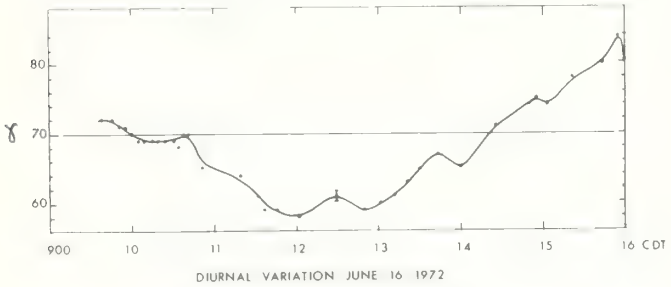


FIGURE 2. A typical diurnal variation as recorded by a stationary magnetometer.

A further procedural matter is determined by the diurnal variation. Since the field changes in time simultaneously everywhere on the site, it is necessary to have a reference against which corrections can be made. If two magnetometers are available then readings can be taken simultaneously in pairs, one at a reference station, the other at the grid points. The difference between the two readings can then be used for maps and profiles. Another survey method is to measure the magnetic field simultaneously at two heights above one point. This cancels out the time variation and gives information on the upward change or gradient, of the magnetic field. Such information can be used to estimate the depth of the anomaly source. This is known as the gradient mode.

The grid of magnetic field values must be manipulated to reveal, one way or another, individual anomalies and patterns of anomalies that suggest archaeological features. We have developed a group of computer programs that can plot various types of level maps, views and profiles, or can plot contour maps by making use of the program SYMAP developed at Harvard. As examples of applications we shall look at two sites surveyed in the summer of 1976.

THE WARD AND GUERRIER TRADING POST

As part of the program to relocate the parking lot and visitor center at the Fort Laramie National Historic Site in Wyoming, it became necessary to determine the position and extent of the Ward and Guerrier Trading Post that operated for a short period of time around 1858.

The area of concern is south of Fort Laramie across the Laramie River. In 1963 a series of test excavations was conducted by Husted which revealed a square structure with some associated smithy artifacts, some foundation structures and a trash pit containing a number of iron artifacts. These are depicted in Figure 3. The datum for that study, however, could not be located so the exact position of those excavation units was unknown.

In the spring of 1976 we conducted a magnetic survey on the site. We layed out over seven 40-foot square grid blocks for surveying and opened up three excavation units as shown in Figure 4. Unit XU1 uncovered a large number of smithy artifacts suggesting this was in the area of Husted's XU3. The magnetic contour map shown in Figure 5 supported this interpretation by showing very large anomalies south of our XU1. The magnetic measurements were obtained on grids with a two-foot unit using one moving and one reference proton magnetometer, and took parts of three days. In addition a strong anomaly in block B suggested Husted's trash pit of his feature A. The strong anomaly in the smith area is near coordinates 36N, 73E (in grid units). The anomaly suggesting the trash pit is at 30N, 31E. Further examination of the map shows an alignment of anomalies running from the southwest region northeast to the northcentral region. All of these results, along with some additional evidence, not discussed here suggests the interpretation of Figure 6, where Husted's map is placed over our magnetic map. The alignment of anomalies is marked by a dotted line.

Our overall interpretation of these results is that the diagonal alignment marks the northwest side wall of a building some 100 feet long containing an interior structure in the central region of the map, and an out-building to the east containing a smithy. The whole magnetic map is shown as a three dimensional view in Figure 7.

KNIFE RIVER INDIAN VILLAGES NATIONAL HISTORICAL SITE

The second example is that of an extensive magnetic survey conducted in August 1976 of several sites on and near the area being acquired to form the Knife River Indian Villages National Historical Site. The sites are a collection of Hidatsa villages near where the Knife River flows into the Missouri River about 50 miles north of Bismarck, North Dakota.

The survey took ten days and covered some 9000 grid points or about 3/4 of a hectare (1.9 acres). I will only discuss one part of this survey, that on an area of house depressions in Sakakawea Village.

Sakakawea Village had been occupied by the Hidatsa for several decades by the time Lewis and Clark wintered over near it in 1804-05. Some 20 or 30 years later it was abandoned. The visible remains consist of a number of circular house depressions on the bank of the Knife River. Figure 8 is a schematic map of these depressions and the layout of 10½ magnetic grid blocks each 20 meters on an edge. The grid unit in this case was 1 meter and again one moving and one reference magnetometer were used.

In order to facilitate examination of the results I have divided these blocks into three parts, each represented by a magnetic contour map with a contour interval of 5.6 gamma.

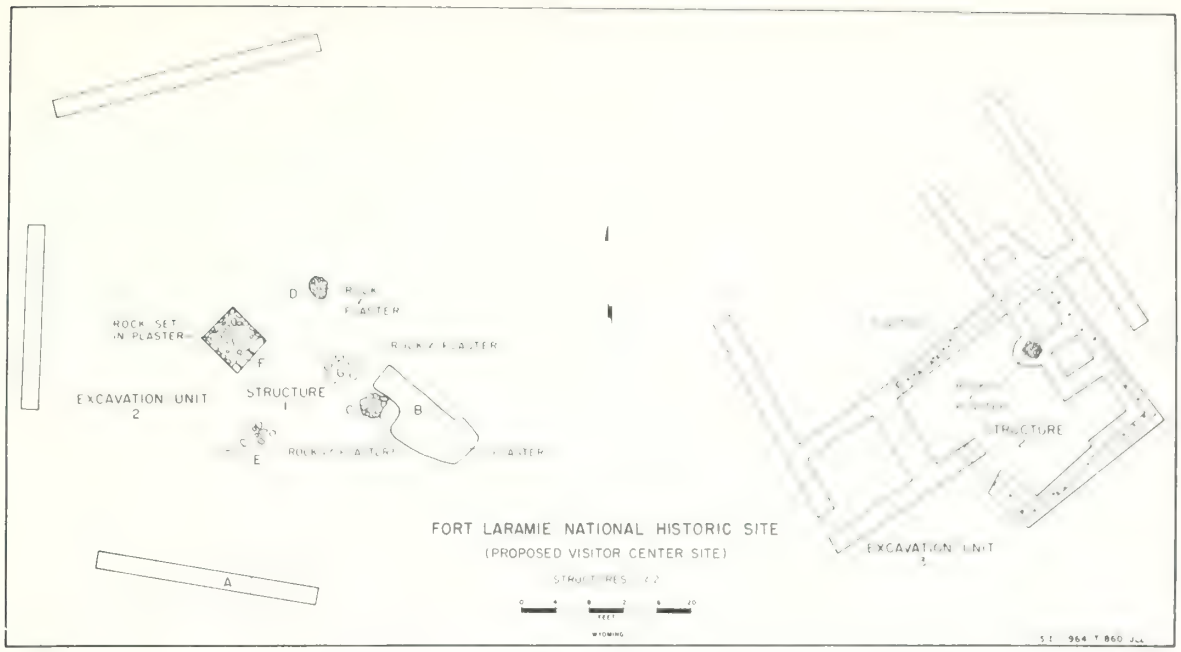


FIGURE 3. Excavation map of the Ward and Guerrier Post, Husted, 1963.

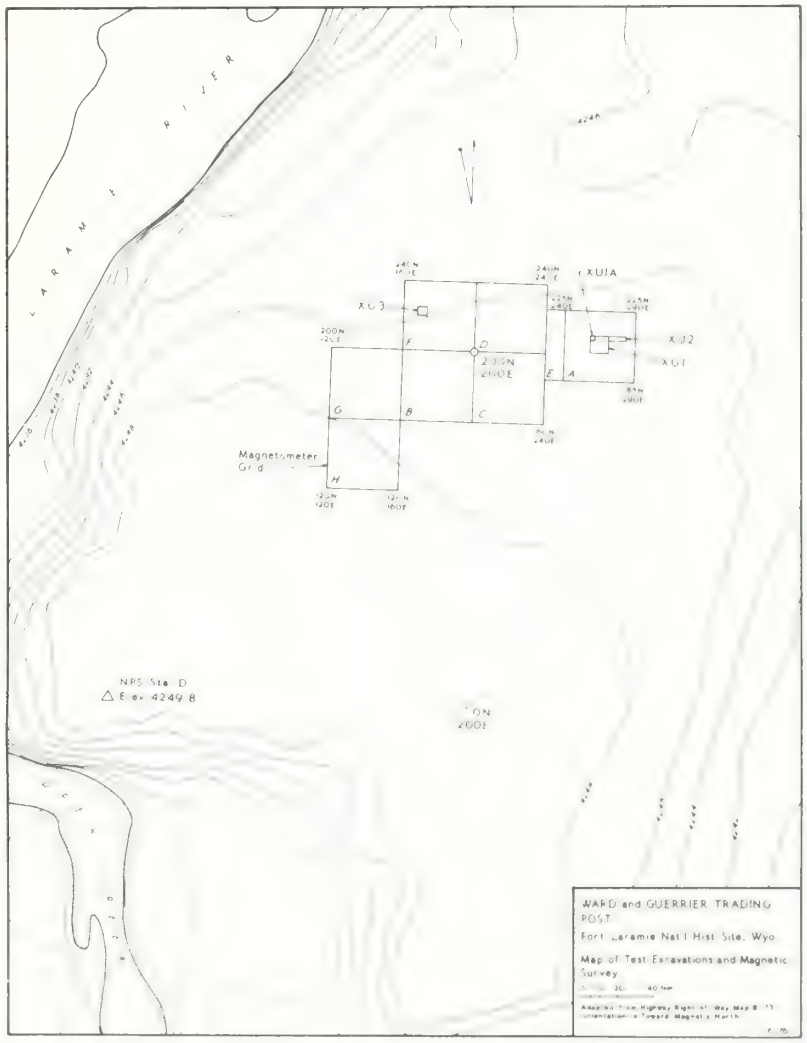


FIGURE 4. Magnetic survey grid blocks and test excavations, Ward and Guerrier Trading Post.

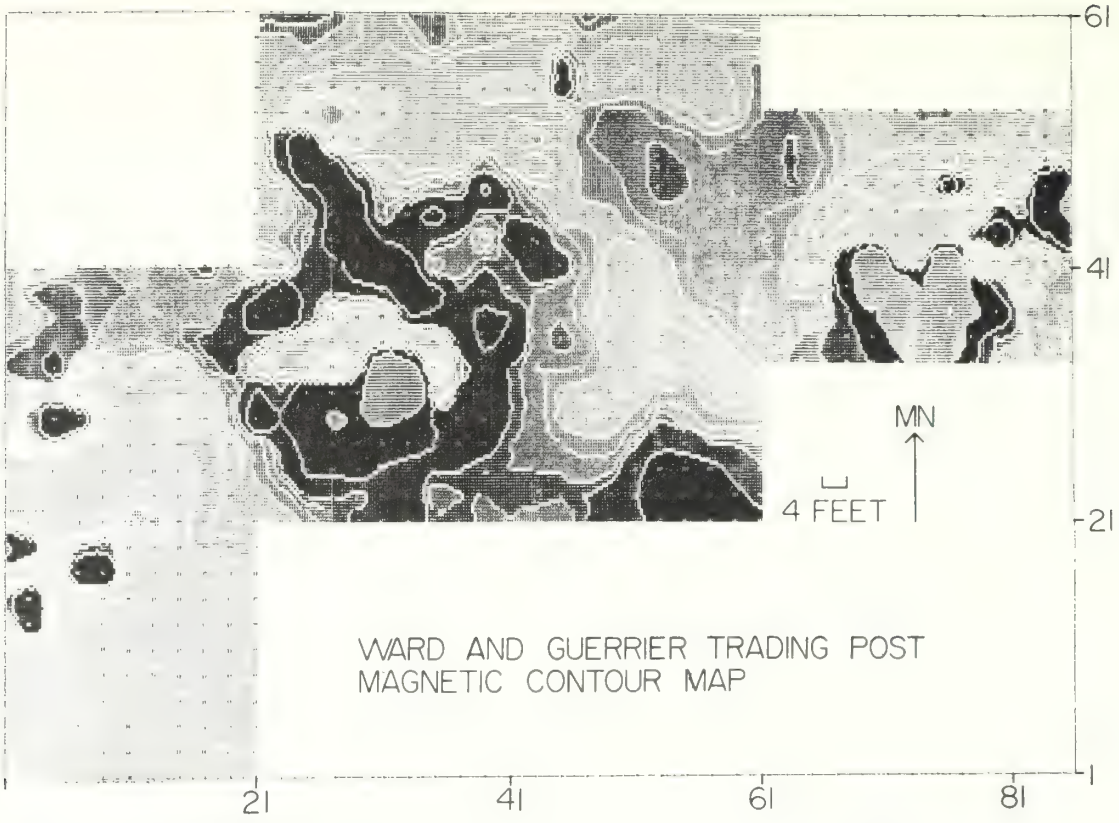


FIGURE 5. Magnetic contour map of the Ward and Guerrier Trading Post.

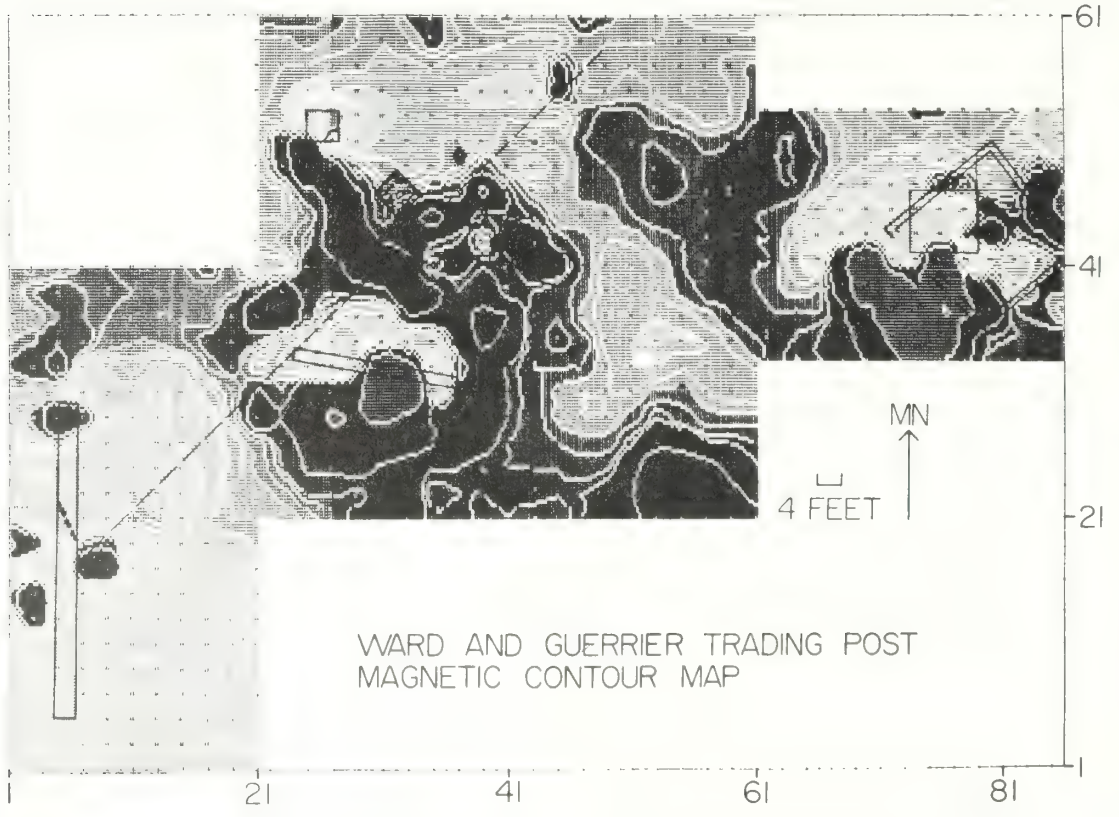
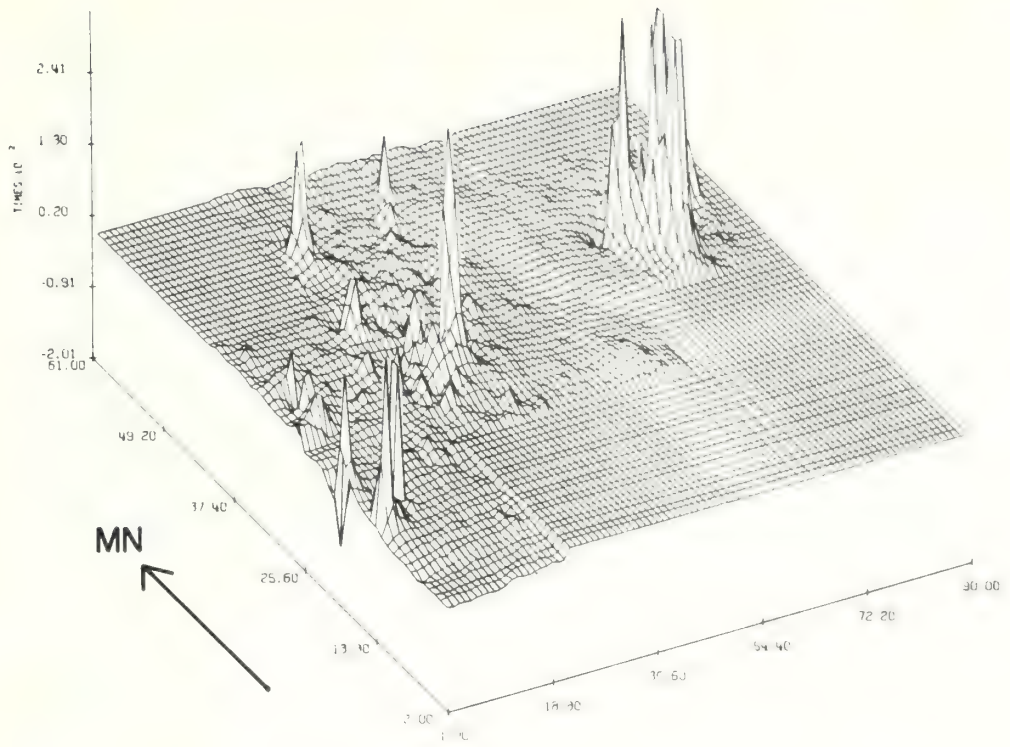


FIGURE 6. Magnetic contour map with Husted map superimposed according to interpretation of the data.



WARD AND GUERRIER TRADING POST

FIGURE 7. Three-dimensional view of magnetic map of the Ward and Guerrier Trading Post.

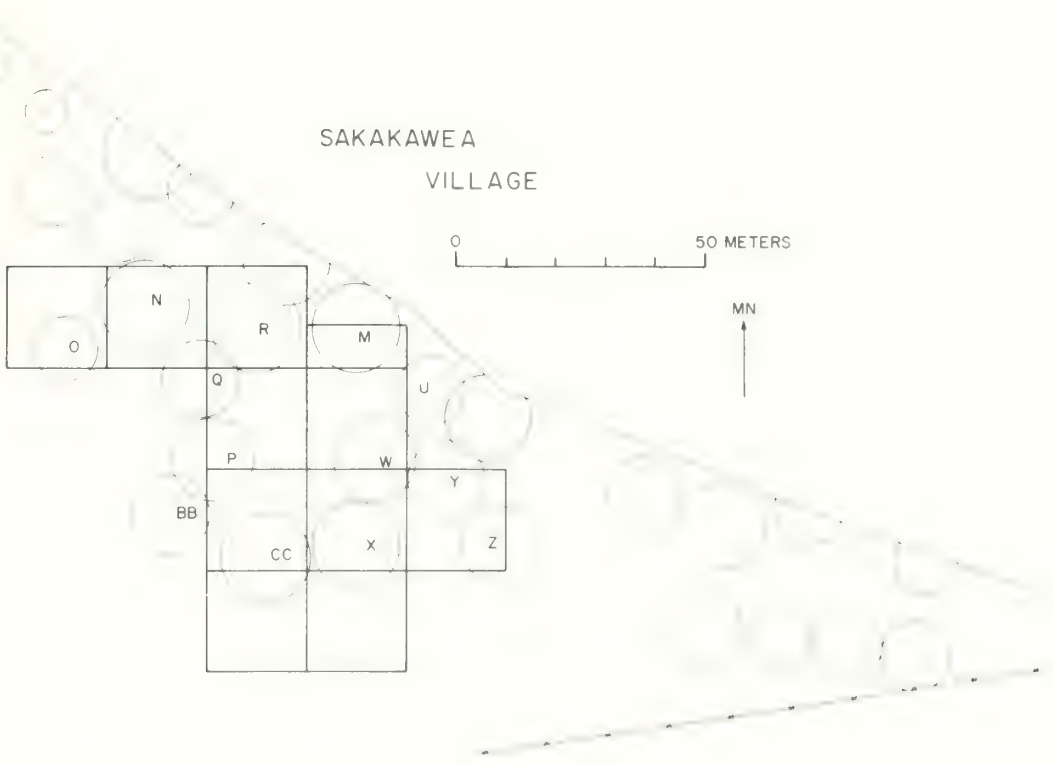


FIGURE 8. Sakakawea Indian Village Site with house depressions and magnetic grid blocks.

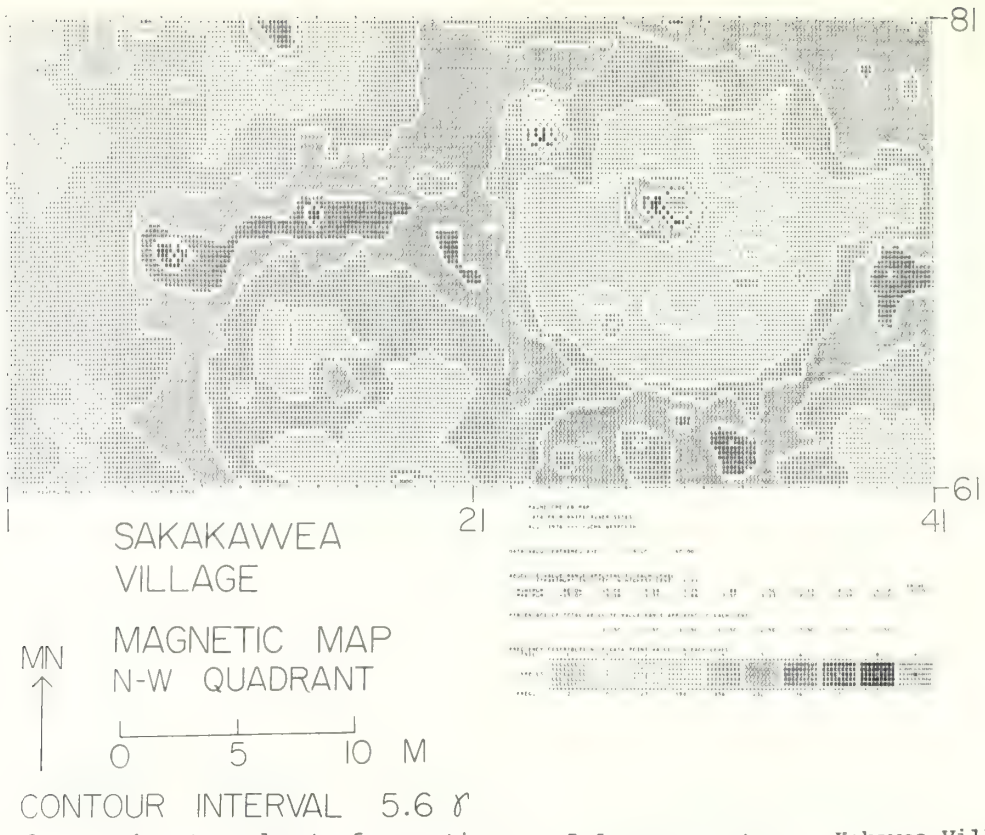


FIGURE 9. Northwest quadrant of magnetic map, 5.6 gamma contours, Kakawea Village.

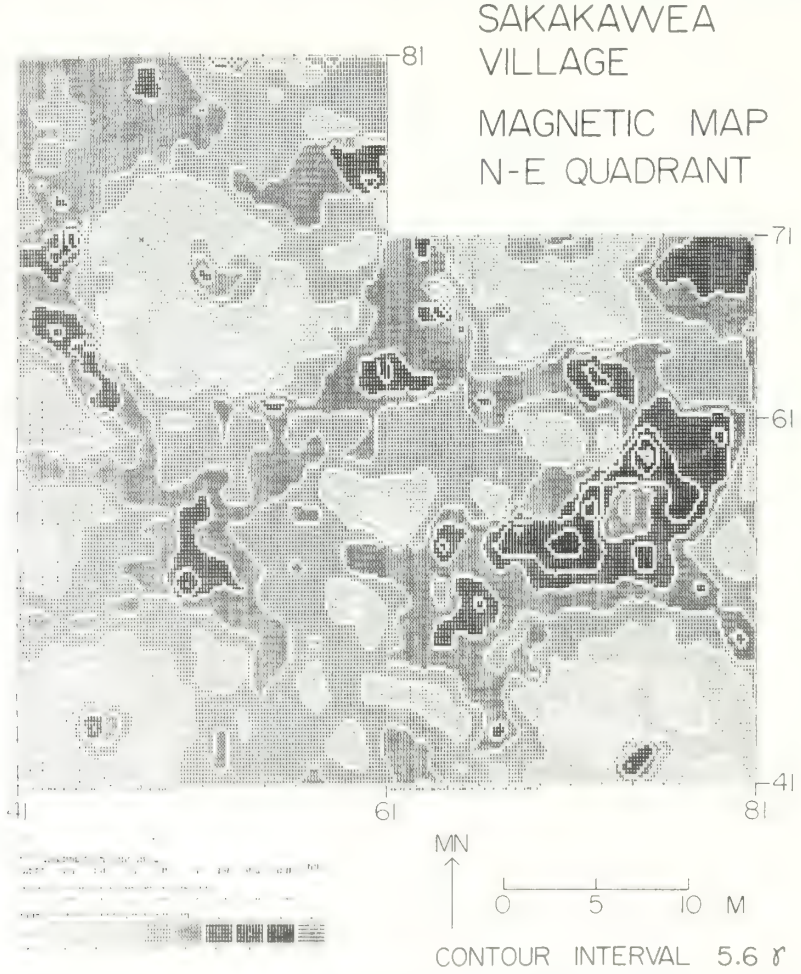


FIGURE 10. Northeast quadrant of magnetic map, 5.6 gamma contours, Sakakawea Village.

The northwest quadrant is shown in Figure 9. Houses N and O are readily apparent with an anomaly in the center in each case due to the fire hearths. These hearths give characteristic anomalies of 30 to 40 gamma because of the fired earth with its thermoremnent magnetism. The entrance to house N can be seen on the east. There are other anomalies in and near the house, probably due to cache pits. Considerably more detail can be seen by using a two gamma contour map.

CONCLUSION

Using the equipment described here, archaeological sites may be surveyed at a rate of up to 2000 grid points per day. Although several days are needed for the analysis of the data, much can be learned about sites without lifting a shovel.

FIGURE 11. Southeast quadrant of magnetic map, 5.6 gamma contours, Sakakawea Village.

It should be remarked at this point that surface topography as well as soil differences contribute to the magnetic signal. In the case of house N the house depression was clearly visible but the position of the entrance was not at all suspected until the magnetic map showed where to look.

The northeast quadrant can be seen in Figure 10. Houses P, Q, R, W and M with their fire hearths are visible. The anomaly in the open region between the houses at 51N, 50E was proved. Burned roof material was found at a depth of 70 to 80 cm and burned earth at about 150 cm suggesting that beneath this fairly flat area was a burned and collapsed house. The southeast quadrant, Figure 11, shows, among other things, a house in the vicinity of 26N, 84E for which there was no visible surface depression.

There is a wealth of information in these maps, most of which have not been examined in detail as yet. Much can be learned about the positions of cache pits, entrances, superimposed houses, fire hearths and other features.

LITERATURE CITED

AITKEN, M. J. 1974. Physics and Archaeology, second edition (Oxford) pp. 207-262.

ARNOLD, J. B. III and G. B. KEGLEY. 1973. A Magnetometer Survey of Hueco Tanks, Texas. Paper presented at 39th Annual Meeting of the Society of American Archaeology, Washington, D. C.

BEVEN, B. 1975. A Magnetic Survey at Les Forges du Saint-Maurice, MASCA Newsletter 11:1.

BLACK, G. A. and R. B. JOHNSTON. 1972. A test of Magnetometry as an Aid to Archaeology. Am. Ant. 28:199.

BREINER, S. and M. D. COLE. 1972. Magnetic Exploration of the Olmec Civilizaiton. Am. Scientist 60:566-575.

TITE, M. S. 1972. Methods of Physical Examination in Archaeology (Seminar Press) pp. 9-24.

THE INUNDATION STUDY: A UNIQUE APPROACH TO CULTURAL RESOURCES MANAGEMENT

Toni Carrell[1]

INTRODUCTION

The Southwest Cultural Resources Center of the National Park Service is the coordinating body for a multi-phase Inundation Study, designed to determine the effects of freshwater inundation upon archeological sites. The focus of the Inundation Study will be the examination of submerged sites, to assess the impact on their data-retrieval potential; the degree of preservation or destruction of archeological remains; and the efficacy of salvage operations versus direct protective measures.

This program has been undertaken to provide agencies involved in land-alteration activities with procedures that will facilitate their land-managing functions in areas where impoundments now exist or are currently being planned. Decisions relating to cultural remains, whether they result in long-term protection, mitigation of adverse impacts, or a combination of procedures, must be based upon thoroughly documented and researched scientific data, rather than upon educated guesses as to how sites are affected once they have been immersed.

The goal of the Inundation Study is to develop management-oriented guidelines for cultural resources, which will provide additioanl information needed to deal intelligently with cultural remains affected by Federal projects, or on Federal lands where the primary impacts will result or currently result from inundation, and enable managers to remain in full compliance with extant environmental legislation. The guidelines will also provide involved agencies with a greater understanding of the resource and a set of alternatives to the questionable techniques of traditional salvage archeology.

HISTORICAL DEVELOPMENT OF THE STUDY

The first proposal for investigations of reservoir-inundated sites came from Donald Jewell (1961). He suggested that it was possible, with specialized techniques, to carry on archeological investigations under water, and that certain kinds of materials might actually be preserved by immersion. Jewell raised the question of whether differential site preservation or destruction occurs within a reservoir in a second article, entitled *Limnoarcheology in California* (1964). In this article, he repeated his concern about the loss of sites due to damming of river valleys, which in some cases, in California, contain the only manifestations of an entire culture, and suggested the application of direct protective measures, such as asphalt caps, to protect sites.

National Park Service involvement in underwater archeology dates from the first underwater archeology project in the United States. In the 1930's, Colonial National Historical Park was investigated under NPS auspices, with diving support provided by the U. S. Navy (Fischer 1974). This project also set the stage for multi-agency cooperation in underwater archeology projects--a practice that has become a trademark of the present Inundation Study. Among later NPS involvements in this nascent discipline was a search for the colonial-period Fort Caroline in Florida in the early 50's (Fairbanks 1952), and the raising of the Civil War ironclad *Cairo* in 1956 (Peterson 1971; Bearss 1964).

National Park Service involvement since the mid-1960's has become increasingly extensive, with NPS personnel conducting full-scale underwater projects. The first in-park underwater archeology program was formulated and authorized in 1969 in the Southeast Region (Fischer and Riggs 1969). Underwater archeology surveys have been conducted at Gulf Islands National Seashore, Fort Jefferson National Monument, and Biscayne National Monument, Florida; Buffalo National River, Arkansas; and Montezuma Castle National Monument, Arizona. In order to conduct these surveys, the NPS developed an internal underwater archeology capability, which has now reached the point where agency personnel are self-sufficient and able to function with their own resources. Underwater archeology capabilities now exist in the Southeast Region, headquartered in Tallahassee, Florida, and the Southwest Region, in Santa Fe, New Mexico.

The initial emphasis of the NPS's underwater archeology program on shipwreck studies has given way to an increased concern for broader management objectives, including concern for prehistoric sites, as well as the development of underwater-remote-sensing techniques to deal with the large areas needing archeological clearance on the Outer Continental Shelf.

In 1974, the Southwest Regional Office Division of Archeology published a model for the management of submerged cultural resources, and specifically addressed the question of reservoir-inundated sites.

> Controversy surrounds the question of what impact inundation has on cultural resources, particularly archeological sites. Many such sites in areas controlled by the National Park Service have been and will be submerged due to dam and other construction projects. This presents a serious management problem . . . proper protection and administration of these resources is contingent on understanding what will happen to them if flooding occurs. Solid systematic data on inundation effects is unavailable at this time and park managers are often forced to make decisions without the benefit of a body of facts to base them on. The situation is further aggravated because evidence is mounting that in many cases archeological sites are being completely destroyed with no effort at mitigation being made. (Lenihan 1974)

Calvin R. Cummings, Chief of the Division of Archeology (now Deputy Chief of the Southwest Cultural Resources Center), recognized the urgency for an in-depth study of the effects of inundation, and because of his concern for resource management and his interest in underwater archeology, he provided the impetus needed for implementation of the study. Through his urging, the previously mentioned submerged resource-management model was developed and disseminated to

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individuals concerned with land modification and impoundments. As reports concerning damage to archeological sites (whether from vandalism, as the result of exposure in wash or drawdown zones, or the direct impacts of inundation) began to appear, they were circulated among concerned Federal archeologists.

Informal discussions among Federal archeologists, and the growing concern for developing a broad management-orientation to cultural resources culminated in a workshop held at the 1975 meeting of the Society for American Archeology specifically designed to discuss submerged cultural remains and the impacts of reservoir impoundment on their data-bearing components. It was the consensus of the assembled group that a formal study should be undertaken to assess the impacts of freshwater inundation on archeological sites, and that this project should be a cooperative, coordinated effort on the part of all Federal agencies involved in land management or modifications in which the primary impacts involved impoundments.

In July 1975, a prospectus for the multi-agency-funded project was drafted by archeologists at the National Park Service's Southwest Regional Office, and sent to Federal, state, and institutionally affiliated archeologists across the United States for comments and recommendations. The preliminary responses of these individuals were reviewed at a second meeting in October. Representatives of the Bureau of Reclamation, U. S. Army Corps of Engineers, Bureau of Land Management, and the National Park Service finalized funding needs, and were able in some cases to offer the use of research facilities and reservoir-construction experts as information resources for the forthcoming study. Final funding commitments were received from all of the above agencies, with the exception of the Bureau of Land Management. Although representatives of the Soil Conservation Service were not present at this meeting, the SCS committed funds for the project.

Because of the National Park Service's long-standing involvement and expertise in underwater archeology projects, and the responsibility assigned the NPS by the Department of Interior to provide aid and assistance to other Federal agencies, it was agreed that the NPS would be the coordinating body for the study. The Southwest Regional Office Division of Cultural Resources (now part of the Southwest Cultural Resources Center) was specifically selected to coordinate the project, because of its active involvement in the development of the Inundation Study, and because it had a functional underwater archeology research team. In late January 1976, an office from which Inundation Study project personnel would operate was set up and Daniel J. Lenihan was designated Project Director.

THE INUNDATION STUDY PROBLEM

The occurrence of cultural remains, both historic and pre-historic, adjacent to water bodies is a recognized phenomenon: human beings have always utilized sources of fresh water. In the New World, river drainage systems have served as loci for human habitations and transportation, and have often delineated cultural boundaries (Williams and Stoltman 1965; Taylor 1964). American archeology has always been closely tied to these drainage systems--to an even greater degree during the latter half of the 20th century, when an unprecedented need arose for the management of water resources resulting from the post-World War II urban and agricultural land boom. Freshwater-impoundment areas have played a major role in the conduct and orientation of American archeology. When a river valley was dammed, and the water level altered, the impacts on cultural material were dramatic and direct and those sites were, to all intents and purposes, withdrawn from the data pool. The response of archeologists to this problem was to salvage as many sites as limited funding and time permitted. Site selection for excavation was reactive, and often based upon a vague notion of significance vis-a-vis material remains or size--and it was generally believed that once sites were inundated, they were not only inaccessible, but totally ruined. Both of these assumptions have been subjected to close scrutiny and reexamination in the past few years.

The obligation of Federal and state agencies to inventory, conserve, and protect cultural remains for the benefit and use of future generations has been expanded, with the passage of a body of law that deals with the environment and cultural remains as finite resources (Public Law 91-190, National Environmental Policy Act, 1969; Executive Order 11593, Protection and Enhancement of the Cultural Environment, 1971; Public Law 93-291, Archeological Conservation Act, 1974). These new obligations have posed a number of problems for land-modification agencies, and for the archeologists who are faced with assessing the significance of and impacts upon resources within a project area that will be impacted by reservoir construction and immersion. Models advanced for understanding the effects of inundation upon archeological sites include both ends of the spectrum, i.e., that sites are preserved and protected, or are destroyed and will "turn into unrecognizable gelatinous masses" (Johnson 1970).

Unfortunately, all of the assertions that have been made up to this point regarding the overall effects of inundation upon cultural resources have been highly speculative, and based upon too little documentation. A number of archeologists have presented research proposals for studies designed to determine inundation effects upon cultural remains (Jewell 1964; Carrell 1974; Lenihan 1974; Cummings 1975, 1976; Garrison 1975a-b; Lenihan et al. 1975; Ruppe and Green 1975). But until the implementation of the Inundation Study, no systematic or in-depth study that could meaningfully address the problem, or cope with the full range of variables involved, has been conducted.

An essential point that must be understood regarding this study is that it is not an anthropological enterprise. It will not seek to answer questions regarding past human activities or their relationship to the environment. It will not produce site reports or listing of artifactual materials, except insofar as the obligation to do so is incurred through the disturbance of cultural remains during the course of investigations. Its purpose and intent are to develop resource management guidelines for those agencies and land managers who deal with cultural resources within the impoundment context. It is an interdisciplinary research project, and one demanding much innovation, because there is no existing substantive data upon which to base recommendations for the management of submerged resources. The information that is acquired during the course of investigations of reservoir-inundated sites will be potentially applicable to sites on the Outer Continental Shelf, sites in submerged or damp caves, and dry sites. The information gathered will ultimately provide for the conservation of, at minimum, a representative sample of the total resource base, regardless of its location or age--conservation extending over the longest possible

time, in a manner that is consistent with expressed national priorities.

GENERAL RESEARCH APPROACH

Not within the scope of this paper is a presentation of the specifics of the entire research design that will be implemented over the 4-year span that the research will be conducted; rather, the paper presents an overview that discusses the general orientation of the research. An Inundation Study Preliminary Report, to become available in early 1977, will contain detailed information on the research design, and the reader is referred to this document.

Two overriding questions are posed in the Inundation Study: What are the impacts of freshwater flooding on archeological sites? What mitigative measures are best suited to cope with these impacts? These questions have been organized in the form of two related models:

Model 1

Several areas of concern are subsumed under Model 1, which is designed to test the association between specific reservoir environments and the impacts, both adverse and beneficial, upon the data-bearing components and physical integrity of archeological sites.

In order to develop an organized framework for assessing the impacts of freshwater flooding, Inundation Study archeologists have, in Model 1, developed a series of testable hypotheses for each of the data-categories, which can be implemented in the field through such activities as recovery and analysis of duplicate samples, re-mapping and visual inspection, and conducting remote-sensing programs. These activities will, in all cases, be conducted on: those now-inundated archeological sites, which, prior to inundation, were investigated, and for which there is adequate documentation to comprise good control-data for the study; or on those sites that have been prepared especially for the inundation project. A comparison of data from post-inundated sites with data-returns available prior to inundation will begin to answer the question of what impacts result from freshwater flooding.

It is assumed that enough of the relevant variables have been isolated, as a result of consultation with experts in reservoir construction, soils, water, and dating analysis, and research by the study archeologists, to establish a meaningful correlation between potential impacts and the causal elements in the reservoir environment. One example from the section in the Inundation Study Preliminary Report, entitled "Impacts on Archeological Dating Techniques," is provided here to illustrate the general approach used--an approach that is designed to be flexible enough to allow for incorporation of emergent problems not previously considered.

Dating techniques are only one of the data-recovery areas specifically considered in the research. The value of these techniques to archeology in terms of understanding past cultures has long been accepted, and the impact of flooding on these techniques is therefore of concern. The dating techniques selected for study include those already used by archeologists, as well as those still in developmental stages. No effort has been made to address the relative values of the procedures in question; rather, the focus of inquiry is on the ability of the procedures to obtain comparable returns from analysis after inundation.

Each dating technique selected was researched by the Inundation Study team, and a hypothesis developed on the basis of this research. For example, examination of available background information concerning obsidian hydration dating resulted in the following hypothesis from the Inundation Study Preliminary Report: "...Analysis of the hydrated face [of an obsidian sample] will yield dates that will not be comparable to samples of similar composition from a non-inundated context." The hypothesis is followed by a series of test implications aimed at empirically testing the hypothesis. One of the test implications for obsidian hydration dating is therefore:

> An obsidian sample surfacially exposed or buried at a shallow depth will exhibit a differential rate of hydration when subjected to inundation, and analysis of the hydrated face will yield a date which is not comparable to an obsidian of similar chemical composition, depth of burial and length of exposure which has not been inundated.

These are basically "if-then" statements, that is, *if* hypothesis is true, *then* certain impacts can be expected (Hill 1970). Whenever possible, these statements and the generating data upon which they are based were reviewed by appropriate experts in the specialty areas addressed by the Inundation Study, and their comments were considered in the finalized hypotheses and test implications.

As results of testing are accumulated, and to the degree to which each test implication is nullified, the hypotheses will be reformulated to reflect the new information, with additional or reorganized test implications to address unforeseen test results. This is not a static, but a continuing, process--one which will be repeated as new information becomes available. The most up-to-date data will be available through a computer information system designed for this purpose. This generating-data/hypothesis/test-implication approach has been repeated in all of the categories of potential impacts that have been isolated in the study.

In order to begin accumulating the comparative baseline data from pre-inundated sites that will be needed to test the hypotheses generated in the research program, a set of "Guidelines for Data Collection and Site Preparation for the Reservoir Inundation Study Project" has been prepared. These guidelines present a standardized format for site-data organization and acquisition, which will facilitate the integration of site information from programs across the Country into the ongoing inundation research, and which will readily lend itself to computerization. Standardization is stressed to eliminate the variable of the influence of data-collection on the results, and will aid in the isolation of different reservoir environments and their impacts. Also presented in the guidelines are selected site-preparation procedures for inundation, which are aimed at monitoring mechanical impacts, and measuring loss of soil color and differential preservation or destruction of features or other remains. Methods for excavation-unit preparation and the placement of relocation devices are included as well. The guidelines are included as a section of the Inundation Study Preliminary Report, and will be available in early 1977.

Model 2

Model 2 is a permutation of, and is dependent upon, the information gathered under the testing programs outlined under Model 1. Measures will be developed in Model 2 whereby the adverse

impacts of inundation may be lessened or eliminated. Concurrent with the field testing program will be the implementation of selected mitigative techniques, which will run the gamut from the direct application of chemical or other coverings to construction of revetments (current or sediment-deflection devices), to the use of plant materials as stabilizers and selected excavation.

Ultimately, a series of resource-management alternatives will be available to planners, land managers, and archeologists who are faced with the immersion of cultural remains and are charged with the responsibility of protecting and conserving environmental and cultural resources.

The information that results from the Inundation Study is not, and should not be, considered an end in itself. Regional plans for the management of cultural resources should be developed, into which the Inundation Study results can be incorporated. Study results cannot be substituted for good pre-project planning and early consultation with archeologists by reservoir managers. The alternatives that will become available through the Inundation Study should, in other words, be considered planning tools, which are essentially useless when not used within an enlightened cultural resource management framework. Only if these alternatives are employed within a management framework will the greatest benefit be derived from the research, and thereby provide for both the long-term protection of and a reasoned approach to, use of the resource.

TECHNICAL APPROACHES USED IN THE UNDERWATER ASPECTS OF THE STUDY

The ability of the Inundation Study to provide information for post-inundation comparative analysis is dependent upon the kind of data-recovery methods employed, as well as upon the relative quality of these procedures. Complete data recording and adequate sample collection are often difficult and complex when an archeological site is dry--and when a site is inundated, the simplest procedures consume more time, and attain an even greater magnitude of difficulty. For example: A site that extends through two old river terraces and changes even 50 feet in overall elevation, when dry, is no problem to map or photograph. When this same site is inundated, the variation in elevation and the addition of even a minimal water column overhead can present a situation in which depth and cold water, coupled with low visibility, become serious obstacles to mapping, photography, and sample collection. The Inundation Study has approached these and other problems in a carefully considered and sometimes unique manner.

Underwater Data-Recovery

The excavation of an archeological site, while ultimately providing additional information about or new insights into past cultures, is essentially a destructive process. Once a site is excavated, the only source of information a researcher has is the records that were kept at the time of excavation. Maps, notes, photographs, and samples (artifactual, soil, osteological, etc.) collected are often the only site remains.

One of the ways in which the Inundation Study plans to monitor the impacts of flooding is through the preparation of post-inundation site maps. Because conventional mapping equipment is generally unsuited for use in underwater environments, the Inundation Study contracted for the construction of special equipment, designed to study specifications, which is adapted for underwater use. A stainless-steel and plexiglass plane-table with adjustable legs and a table-top that can be leveled is one of the pieces of mapping equipment that was built. This plane-table is used in conjunction with a modified transit, which has had the optics removed and replaced by cross-hairs. A heavy stainless steel straight-edge was attached to the base of the modified transit to stabilize it and enable it to stand alone. These changes permit its use as a transit or alidade. A 2.5 meter plexiglass stadia rod, marked in 10-centimeter increments, is another piece of modified mapping equipment used by the Inundation Study. This stadia rod is equipped with an internal energy source that powers two small lights. The lighted stadia rod proved its value when it was used for mapping in the low-visibility waters of Amistad Reservoir. This mapping system allows for maximum flexibility, in that elevation and distance can be plotted on the plexiglass plane-table top, and immediate visual feedback on mapping can be made available. The materials from which the table is constructed are such that it can be left under water for an extended period with little or no ill effects. The table has an opaque, white plexiglass "false" top, which can be removed without disturbing the table base, or without getting it out of level, if brought to the surface at the end of each day's mapping where information can be transferred to a permanent map.

The mapping equipment is used in conjunction with wireless diver-to-diver communications. This increases efficiency in the mapping operation by permitting the diver using the transit to quickly communicate any instructions or questions to the stadia diver. Communications with the surface are also possible with the wireless unit, which allows the surface support crew to monitor the activities of the mapping team, and to record pertinent information as needed.

In extremely low-visibility water, or in what are essentially blackout conditions, another approach to site mapping is required: The Inundation Study has purchased a fathometer, which can be calibrated for freshwater use. When the fathometer head is positioned to provide horizontal, rather than the usual vertical, distance measurements and is mounted on a tripod with vernier, or on the transit and used with the plane table, angles can be turned and the site can be mapped. When a full-face mask, equipped with diver-to-surface communications, is used in conjunction with the fathometer, the efficiency of surface machine recording is increased. The diver wearing the mask can communicate the progress of the mapping to the surface support crew, who can then "mark" each point as it is automatically recorded by the surface component of the machine.

In addition to employing standard photographic and written recording of site information, the Inundation Study has tested the viability of using an underwater video-camera recording system. This video-recording technique has been successfully used at excavations in Warm Mineral Springs, Florida, by the Underwater Archeological Research Section of the State Board of Archives, History and Records Management division, and is being considered for use as a standard tool in the study. One of the advantages of video-recording, in addition to providing a permanent record of all activities, is the ability of the video-camera to "see" through turbid water much better than the diver. The potential use of this technique will allow for photogrammetric recording, when used in conjunction with a portable plexiglass grid. The Inundation Study currently has a 1-meter-by-1-meter grid which has been strung to create 10-centimeter-square divisions. When the grid is

located relative to a datum point, the video-camera can scan the grid, quickly and accurately recording the location of features, artifacts, sample collection areas, and so forth. The grid is constructed so that it can be easily moved, and in this manner a permanent video record can be made of an area, with a minimum of wasted effort or time. If still-photographs of taped activities are required, and are not readily available or were not previously taken, they can be "lifted" from the tape through the video monitor.

The grid has been constructed to accommodate a removable photo tower. An underwater camera, fitted with a 21-millimeter distortion-corrected lens, can be mounted on the tower, and the entire grid can be photographed. This combination of the grid and tower readily adapts itself to quick, error-free photogrammetric mapping.

The full-face mask with hard-wire communication, when used with the underwater video camera, has the additional advantage of providing for complete provenience control in sample collecting. This system also permits the non-diving or non-deep-diving scientist or archeologist to visually inspect the site and sample collection areas by watching the surface monitor. Communication between the diver and surface is instantaneous, and samples can be collected to conform to specifications relayed by the topside researcher.

Both the hard-wire and wireless communications equipment can be used for permanent recording of provenience data, when samples are collected and/or the information is transmitted to the surface for recording on sample collection data cards.

Diver Training and Safety

The Inundation Study core team of archeologists is comprised of individuals who have a combination of traditional archeological background and experience in underwater archeology. In addition to their research responsibilities, they also fulfill responsibilities as professional SCUBA divers.

A rigorous year-round safety and skills maintenance program has been instituted, and is mandatory for all team members. This training is critical, because of the deep, cold diving often required, and the use of sophisticated equipment in the Inundation Study.

Decompression diving, a serious undertaking requiring careful pre-dive planning and preparation, can be dangerous even at sea-level for the untrained. At higher elevations, compensation for the decrease in ambient air pressure poses an additional problem. Because many of the reservoirs that the Inundation Study will use for research lie far above sea level, special decompression practices are used by Inundation Study divers. High-altitude diving and decompression procedures are not new; several models have been proposed (E. R. Cross 1970; C. L. Smith 1972; Lenihan and Morgan 1975). The Inundation Study employs the procedure set forth by Lenihan and Morgan.

In addition to using altitude-compensating decompression practices, after deep or extensive dives, the team uses pure oxygen for all decompression stops 20 feet and above. Pure oxygen increases the gas exchange rate in the body, and builds in an additional safety margin. Oxygen decompression has been successfully used in the Warm Mineral Springs excavations, where over 1,000 hours of diving have been completed by the researchers, with no accidents (Murphy 1976).

Along with the special training outline above, the Inundation Study team participates in a continuous program of training in diver rescue and advanced first-aid, lift operations, use of line reels and underwater riggings, silt-control techniques, working in low-visibility water approaching blackout conditions, cold-water diving, and deep diving. In later phases of the research program, the karst areas of the United States will be incorporated into the investigations, because of the long period of time various cultural remains have been submerged in the underwater caves located there. In anticipation of this work, specialized underwater-cave training has been instituted to prepare the diving team.

A point that needs to be emphasized here is that the underwater skills being developed by team members are not an end in themselves--but are rather considered tools of the trade, much as archeological or anthropological theory or use of a Marshaltown trowel are considered tools. In this regard, these skills are stressed not only for the safety of the divers, but for the efficient operation of the Inundation Study.

CONCLUSION

The conservation ethic--an ethic that has become integral to most cultural resource management schemes is based in part upon the preservation of a representative sample of sites within a total resource base. The range of prehistoric and historic sites within any given area will be varied, because it has been shaped by the interplay of a number of environmental and societal factors. The concentration of inventory, recording, excavation, and planning efforts on obvious occupation areas, burial-grounds, standing structures, or settlements of the dominant ethnic groups will skew both our understanding and interpretations of these cultures and their roles through time. Total cultural resource management, therefore, should include special-use prehistoric and historic sites, and those sites that represent the poor, the non-literate, and the small ethnic groups in a society.

This conservation ethic must be extended to include sites that are now, or will be, under water. Archeological remains on the Continental Shelf, or in rivers, submerged or damp caves, reservoirs, and sinkholes should not be discounted, or considered to have less potential for good anthropological data recovery. These sites are cultural resources of the same genre and value as pueblos or historic battlegrounds, and they must be considered within an enlightened regional framework. The results of the Inundation Study will serve as a viable management tool that should be integrated into regional and long-term planning processes in a manner that provides for the reasoned and intelligent management of resources in impoundment areas.

LITERATURE CITED

BEARSS, EDWIN. 1964. Underwater Archeology and the Cairo. In Diving into the Past. pp. 12-18.

CARRELL, TONI. 1974. Effects of Inundation. A research proposal for underwater archeology. University of California, Santa Cruz.

CUMMINGS, CALVIN. 1975. Summary of National Park Service Underwater Archeological Activities. Paper presented at the annual meeting of the Society for American Archeology.

_____. 1976. A proposed study of the Effect of

Inundation on Cultural Resources. Paper presented at the Seventh International Conference on Underwater Archeology.
FAIRBANKS, C. H. 1952. Archeological Exploration at Fort Caroline National Historical Park Project, Florida. Unpublished manuscript. Southeast Archeological Center, National Park Service, Tallahassee, Florida.
FISCHER, GEORGE. 1974. The History and Nature of Underwater Archeology in the National Park Service: A Model for the Management of Submerged Cultural Resources. pp. 3-8.
FISCHER, GEORGE and MARION RIGGS. 1969. Prospectus for Underwater Archeology. U. S. Department of the Interior, Office of Archeology and Historic Preservation. Washington, D. C.
GARRISON, E. G. 1975a. A Qualitative Model for Inundation Studies for Archeological Research and Resource Conservation. Plains Anthropologist 20(7), part 1:270-296.
_____. 1975b. A Research Design for Quantification of Inundation Effects: Ozark Bluff Shelters Located Along Veaver Reservoir. Unpublished Manuscript. Arkansas Archeological Survey.
HILL, JAMES N. 1970. Prehistoric Social Organization in the American Southwest: Theory and Method. Reconstructing Prehistoric Pueblo Societies. pp. 11-59.
JEWELL, DONALD P. 1961. Freshwater Archeology. American Antiquity 26(3):414-416.
_____. 1964. Limnoarcheology in California. In Diving into the Past. pp. 27-31.
JOHNSON, JERALD. 1971. Archeological Sites as Non-Renewable Resources. Proceedings of the Symposium on Environmental Resources Development, June 14-15. Institute of Technology and Society. Sacramento State College, California.
LENIHAN, DANIEL J. 1974. Inundation Studies. Underwater Archeology in the National Park Service: A Model for the Management of Submerged Cultural Resources. pp. 28-30.
_____. 1975. Draft Prospectus for a Multi-Agency Cooperative Research Project to Determine the Effects of Inundation on Cultural Resources in the United States. U. S. Department of the Interior, National Park Service, Southwest Regional Office, Division of Cultural Resources. Santa Fe, New Mexico.
LENIHAN, DANIEL J. and KEN MORGAN. 1975. High Altitude Diving. U. S. Department of the Interior, National Park Service, Southwest Regional Office, Division of Cultural Resources. Santa Fe, New Mexico.
MURPHY, LARRY. 1976. Personal communication to author. Underwater Salvage and Field Agent. State of Florida, Board of Archives, History and Records Management, Underwater Archeology Research Section.
PETERSON, H. L. 1971. USS Cairo. U. S. Government Printing Office. Washington, D. C.
RUPPE, R. J. and D. F. GREEN. 1975. Feasibility Study: Effects of Inundation on Cultural Resources. A research proposal for Roosevelt Lake, Arizona. Arizona State University, Tempe, Arizona; and Department of Agriculture, Forest Service, Albuquerque, New Mexico.
SMITH, C. L. 1975. Another Wrinkle in Altitude Diving. NAUI News, February. (Newsletter of the National Association of Underwater Instructors).
TAYLOR, WALTER W. 1964. Tethered Nomadism and Water Territoriality: An Hypothesis. Sobretiro del Congreso Internacional de Americanistas Mexico, 1972. Mexico.
WILLIAMS, STEPHEN and JAMES B. STOLTMAN. 1965. An Outline of Southeastern United States Prehistory, with Particular Emphasis on the Paleo-Indian Era. Quarternary of the United States. Edited by Wright and Frey. pp. 669-683. Princeton University Press, Princeton, New Jersey.

COMPOSITE MAPPING FOR ARCHEOLOGY

John E. Ehrenhard[1]

INTRODUCTION

The limited analytical capabilities of single topic maps can many times be overcome through composite mapping. This allows for the fusion of spatially unaltered data sets from two or more maps into a single graphical model. Hereto unnoticed relationships may be more readily observed by the combination of the disparate information.

The relocation of Fort William, Cumberland Island, Georgia, and land accretion and erosion formations at Cape Lookout, North Carolina, are two examples of composite mapping discussed in this paper.

Maps are graphic models of reality which may be representational, conceptual, or analytical. Single topic maps have been of great utility to archeologists but we have relied heavily on those that are representational and conceptual; only recently have maps been used as analytical models which are geared to problem solutions.

The limited analytical capabilities of single topic maps can many times be overcome through a technique known as composite mapping. This allows for the fusion of spatially unaltered data sets from two or more maps into a single graphical model. Hereto unnoticed relationships may be more readily observed by the combination of the disparate information. Composite mapping produces conceptual and analytical models as well as some generalization of topographic reality.

One can produce composite maps manually, however, this method has several drawbacks:

1. Excessive time.
2. The number of maps which can be handled efficiently is small.
3. The maintaining of consistent and accurate quantitative judgments is not possible.

Another method with more flexibility is the manipulation of data sets through a computer. Compositing in this manner involves the conversion of analog measures (i.e., length) into cartesian coordinates off of the maps being used. A device known as a digitizer codes the graphic images into a digital computer usable form. (See Keates 1973:182-194 for details.)

In general the coordinate system is formed by a series of line sets which intersect each other to form a network when plotted. The necessary criteria being (Maling 1973:19):

1. that the two sets of lines are distinct from each other.
2. that every line of one set should intersect every line of the other set at one point only.
3. that no two lines of the same set intersect each other.

Information about position is obtained by tracing map detail with the digitizer. This information is recorded and stored on magnetic tape according to the individual X, Y coordinate values, hence the latitude and longitude of a topographic map is converted into X, Y coordinates (Figure 1).

To reproduce the map details into the desired form it is necessary to convert back from the X, Y system. This is usually accomplished by digitizing control points on the maps which determine the translation, rotation, and scale changing components of the transformation (Maling 1973:28).

Several examples illustrating the utility of such techniques are given: Beginning around 1700, Spanish grip on the South Georgia coast began to fail; aboriginal populations were declining as a result of smallpox or in response to English pressure. The English colonization of the Carolinas began to force a Spanish retreat southward to their stronghold in St. Augustine, Florida. Their fate was sealed indirectly in 1733 when James Edward Oglethorpe founded the colony of Georgia (Savannah). With this establishment completed Oglethorpe took cognizance of the sea islands to the south and saw them as bastions of defense and staging areas for attacks on Spanish Florida.

Fort Prince William was one of two forts Oglethorpe constructed on Cumberland Island, Georgia, for this purpose and it was to play an important role in the struggle between Spain and England during the War of Jenkins Ear (1739-1743).

During the cultural resource assessment of Cumberland Island National Seashore by Southeast Archeological Center, efforts were made to locate Fort William (Ehrenhard 1976a). Published descriptions fail to accurately pinpoint its location and several early maps giving the location lack sufficient detail. These were scrutinized, but the only conclusions that could be drawn were that Fort William was somewhere along the south end of the island.

Accordingly, our efforts were concentrated along the southern portion. It was decided that the remains of the fort would either be near the fresh water springs southeast of Beach Creek or within the heavily forested sand dunes nearer the tip. Hundreds of man-hours were spent in the attempt to locate this feature, all to no avail.

Subsequent archival research resulted in our finding an accurate map of Cumberland produced in 1802 by John McKinnon. This map, which was drawn up to settle a property boundary dispute, points out the location of Fort William (Figure 2). One drawback of this map was that it was 12 feet long. It also shows an island with a considerably different topography than presently viewed. By using the techniques described earlier the McKinnon chart was reduced in scale to equal that of a 7.5 minute quad. The composite map indicated that we had not been looking in the proper location and that Fort William is actually

[1]National Park Service, Southeast Archeological Center, Tallahassee, Florida.

Digitising: Irregular Shape

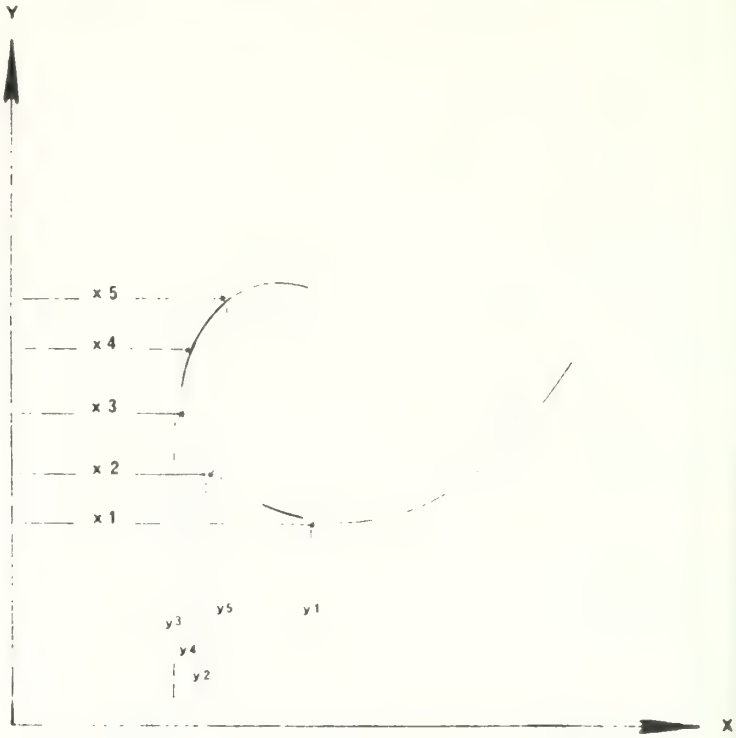

FIGURE 1.

Shoreline Changes
in the Area of
Cape Lookout

FIGURE 2.

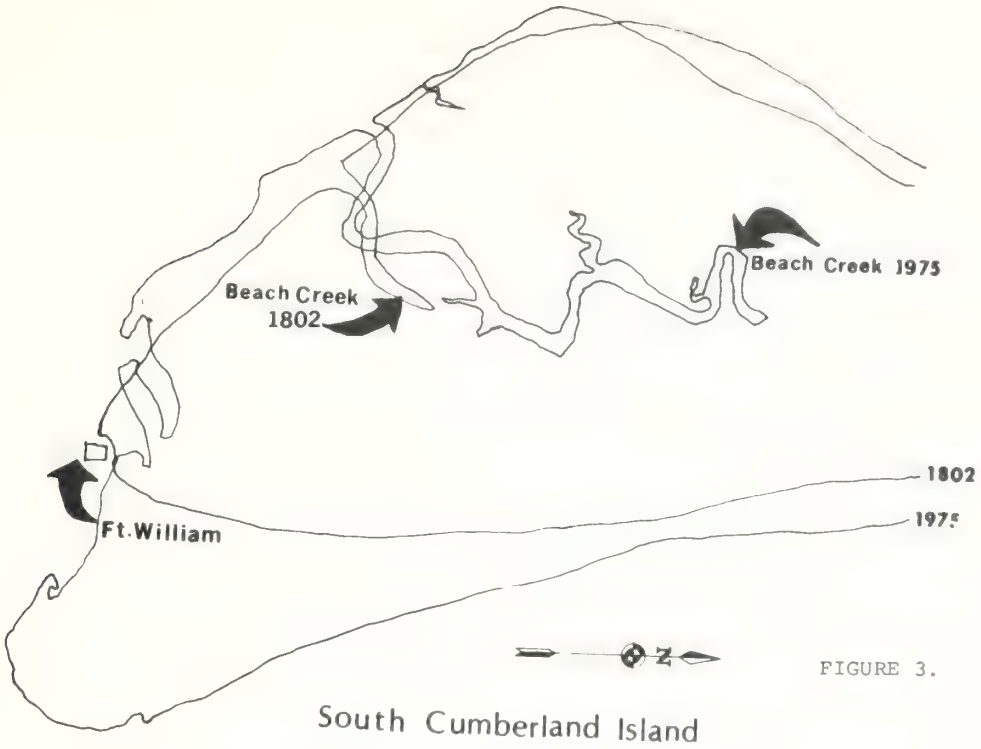

FIGURE 3.

South Cumberland Island

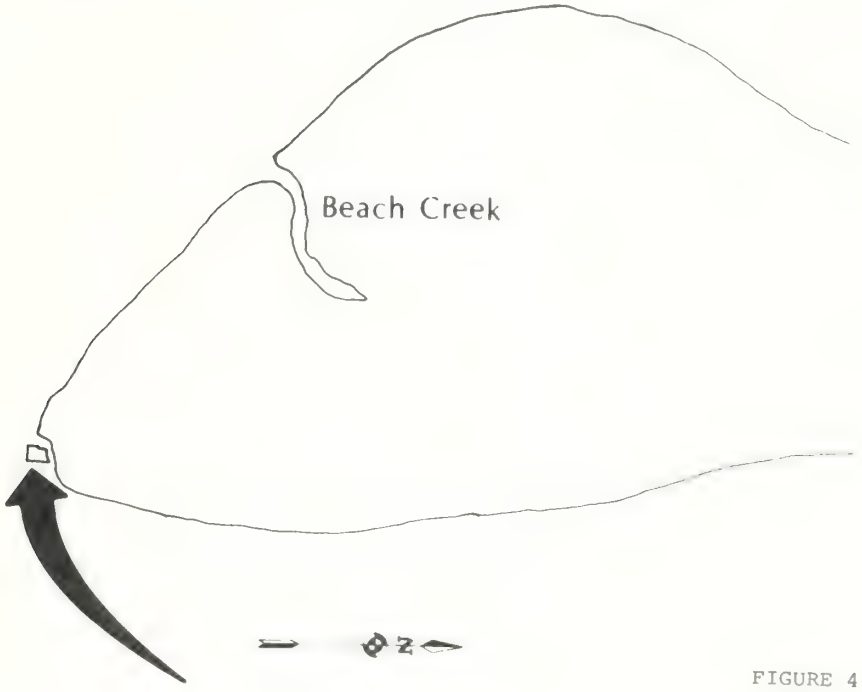

FIGURE 4.

Ft. William

Cumberland Is. ca. 1800

out in the marsh flats (Figure 3). A check of the area has revealed a number of bricks and fragments of china. Research this coming summer will hopefully accurately establish the location of the fort.

Plotting the location of Fort William also generated some edifying supplementary data concerning erosion, accretion, and dune migration. This information will be of benefit to park planners as they study possible locations of visitor facilities.

The ability of these methods to show erosion and/or accretion patterns was put to use during the cultural resource inventory of Cape Lookout National Seashore, North Carolina (Ehrenhard 1976b). Here the geomorphic processes which create and maintain the barrier islands of the seashore constantly modify the land mass which is gradually being rolled over and pushed back to the coastal plain. Major topographic changes can occur within a few days during a heavy storm.

The islands that make up the outer banks are constantly eroding and rebuilding as they slowly migrate toward the mainland. While the barrier islands are attuned to these rapid changes and have a naturally built-in "dynamic stability," cultural features are not so flexible and are forever lost as the islands continue to evolve.

Knowing that considerable topographic change has occurred at Cape Lookout an attempt was made to plot this movement so that priority could be given those portions that had suffered the least amount; this would provide us with a better chance of locating undisturbed cultural manifestations.

A time series of maps dating from 1861 to the present produced the following plot giving changes along the cape. (Figure 4).

It is easy to understand why cultural material is generally found on the beaches and in the beach wash. It is found eroding from sand dunes and in blowouts. The mobility of the land mass is amply illustrated. This mobility does not allow for continuity or stratigraphic integrity of aboriginal features.

Using composite maps in such a manner illustrates a method of determining high priority survey areas before one initiates the survey. Such a project is currently underway at the Southeast Archeological Center. It involves the cultural resource inventory of Big Cypress National Preserve.

In this case, composite maps will be produced illustrating topographic, soil, geologic, and vegetative details. Aboriginal site descriptions containing this type of information will be entered into the equation. The net result, we hope, will be a projection of possible areas of cultural activity within the 570,000 acre preserve. Advance information of this nature will be of considerable value as available research funds limit out time in the field.

CONCLUSION

Composite mapping shows great promise for the archeologist who is faced with cultural resource inventories of large areas or those which are constantly being modified. The technique provides advance data which can be used to generate comprehensive research designs; this in turn allows for balanced allocation of time and funds. Above all it provides for a more controlled and systematic reconnaissance of the area in question.

LITERATURE CITED

EHRENHARD, JOHN E. 1976a. Cumberland Island National Seashore: Assessment of Archeological and Historic Resources. MS, Southeast Archeological Center, Tallahassee, Florida.

_____. 1976b. Cape Lookout National Seashore: Archeological and Historic Resources. MS, Southeast Archeological Center, Tallahassee, Florida.

KEATES, J. S. 1973. Cartographic Design and Production. Lowe and Brydone (Printers) Limited, Thelfor, Norfolk, England.

MALING, D. H. 1973. Coordinate Systems and Map Projections. George Philip and Son Limited, London.

IMPLICATIONS OF RAINFALL RECORDS AT MESA VERDE NATIONAL PARK

J. E. Ingmanson and M. A. Colyer[1]

Mesa Verde National Park, in southwestern Colorado, has always received a great deal of public attention with respect to changes in climate, particularly rainfall. Tree ring records tell us that the last quarter of the thirteenth century was a period of precipitation deficiency, and this climatic phenomenon has been cited as the impetus for the abondonment of the northern part of the American Southwest by the cliff-dwellers. This "Great Drought" has become a part of historical literature. For this reason Mesa Verde comes quickly to mind as a spot which might react with unusual sensitivity to a widespread fluctuation in the weather. Precipitation is one aspect of the weather on which we have some data.

Measurements of precipitation are made daily in the Park Headquarters of Mesa Verde National Park. Records of these measurements in the form of monthly summaries have been maintained in the park archives since 1922. These same data are published by the National Oceanic and Atmospheric Administration (1975) in *Climatography of the United States No. 20* for the period from 1951 to 1974.

A set of precipitation records covering a period of over fifty years at Mesa Verde can be examined with respect to several foci of interest; two questions are considered here. First of all, how does the present situation compare to models of the past? Researchers have described Mesa Verde as a location where a considerable prehistoric farming population flourished during the tenth, eleventh, twelfth, and part of the thirteenth centuries. Abandonment of the area is apparent in the latter part of the thirteenth century, and unfavorable climate, characterized in particular by deficient rainfall, has been suggested as a significant vector. Is it likely that current rainfall patterns are illustrative of either the period of occupation or abandonment?

Secondly, there are climatologists today who suggest that an important change in world climate began to take place about 1950. Some have described this change as similar to the putative change in the late thirteenth century. Since archaeological evidence suggests that the thirteenth century change may well have manifested itself at Mesa Verde, do modern records illustrate a change starting about 1950?

David Baerreis and Reid Bryson (1965:215-216) have described a model for climate between roughly A.D. 800 and A.D. 1250 which they call the Neo-Atlantic episode. In their description: "The Southwest was warmer; glaciers disappeared from the United States portion of the Rocky Mountains; and extensive gullying began in the valleys of the Colorado Plateau and the Rio Grande area, apparently in response to increased summer rainfall. During this time the Anasazi corn farmers, using the summer rains expanded to their maximum extent." In the ensuing Pacific climate episode "summer rains diminish in the Southwest" and "glaciers once again were found in the U.S. Rockies as far south as New Mexico."

Schoenwetter and Eddy (1964:118) characterize the period of 800 to 1100 as one of "summer dominant storms." This they feel is similar to the situation today in the Navajo Reservoir District (50 miles southwest of Mesa Verde). At a type station here, 34.8% of annual precipitation if recorded in three summer months (June, July, and August) as opposed to 15.5% in three winter months (December, January, and February) (Dittert et al. 1961:16). Here the seasonal difference in precipitation is readily discernable.

At Mesa Verde the 53-year record of precipitation shows 27% to occur in the three winter months (December, January, and February) and 26% in the three summer months (June, July, and August). A little more precipitation comes in the winter than in the summer. Although summer thunderstorms are conspicuous at Mesa Verde, this area is not a good illustration of a current summer dominant rainfall pattern in the Southwest.

If the climate at Mesa Verde during the period of Anasazi occupation resembled the climate model for the Southwest in general, then present climate is somewhat different from that which would have prevailed during the period from A.D. 800-1250. If, however, the climate of Mesa Verde today is similar, with respect to precipitation, to that which prevailed during the Anasazi occupation, then Mesa Verde weather must be considered atypical to the general pattern for the Southwest. In either case Mesa Verde provides a poor illustration of conditions which presumably were widespread.

Another model for the description of our climate suggests that the earth has entered into a period of cooling that commenced about 1950 (Calder 1974). In such a cooling period we might expect a northerly precipitation pattern to move southward.

In the northern part of the Southwest a winter type precipitation pattern with Pacific derived moisture might linger and impede the annual encroachment of anticyclonic storms from the south with their moisture from the Gulf of Mexico. This might well show up as a trend away from a summer dominant rainfall pattern toward a pattern of winter dominant precipitation. Such shifts are postulated for past centuries in the Navajo Reservoir district (Schoenwetter and Eddy 1964:118).

If such a pattern has commenced in the Southwest it is not yet evident at Mesa Verde. The rainfall records at Mesa Verde show only modest fluctuations, and these are away from the direction that the model would lead us to expect (Table 1).

From 1923 through 1950 winter precipitation (December through February) accounted for 28% of the annual totals. From 1951 through 1975 winter precipitation averaged 27% of total. June through August accounted for 25% of the annual precipitation in the early period and 27% in the later period.

As stated earlier figures for the station in the Navajo Reservoir District show 34.8% of the

1 Mesa Verde National Park, Colorado 81330.

TABLE 1. Summer and winter precipitation at Mesa Verde National Park, before and after January 1, 1951.

	1923-50	1951-75
Average Annual Precipitation	18.6 in.	17.7 in.
Dec.-Feb.	28%	27%
Jun.-Aug.	25%	27%

annual precipitation in the summer months (June through August) and 15.5% in the winter months (December through February) (Dittert et al. 1961: 16). This is considered to be an example of summer dominant precipitation. At periods in the past piror to A.D. 800 and subsequent to A.D. 1550, Schoenwetter and Eddy postulate that a contrasting winter dominant precipitation pattern prevailed (Schoenwetter and Eddy 1964:118). Obviously this would require a change in rainfall dissimilar to the observations at Mesa Verde.

The data from Mesa Verde do not provide evidence of a relative increase in winter precipitation (and a relative decrease in summer rainfall) that might be expected to accompany widespread climatic cooling since 1950.

Despite Mesa Verde's prominent position in literature, the precipitation records from the park suggest that this area does not provide us with a good illustration of past weather in the Southwest or current weather trends.

LITERATURE CITED

BAERREIS, DAVID A., and REID A. BRYSON. 1965. Climatic Episodes and the Dating of the Mississippian Cultures. The Wisconsin Archeologist, vol. 46, No. 4, pp. 203-220. Milwaukee.

CALDER, NIGEL. 1974. The Weather Machine. Viking Press Inc., New York.

DITTERT, ALFRED E., JR., JIM J. HESTER, and FRANK W. EDDY. 1961. An Archaeological Survey of the Navajo Reservoir District Northwestern New Mexico. Navajo Project Studies II, Monographs of the School of American Research and the Museum of New Mexico, no. 23. Santa Fe.

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION. 1975. Climate of Mesa Verde National Park. Climatography of the United States, no. 20. Asheville.

SCHOENWETTER, JAMES, and FRANK W. EDDY. 1964. Alluvial and Palynological Reconstruction of Environments, Navajo Reservoir District. Navajo Project Studies XI, Museum of New Mexico Papers in Anthropology, no. 13. Santa Fe.

THE IMPACT OF MAN ON NATIONAL PARK SERVICE AREAS FROM PREHISTORY TO THE PRESENT

John L. Cotter[1]

THE ADVENT OF MAN IN NORTH AMERICA

Without doubt the dominant animal in every National Park Service area, if also one of the endangered species, is man. This has not necessarily always been the case, but it certainly has after the area was acquired by the Service. With this fact primarily and firmly in mind, we may consider further the role of man in the National Parks.

In nearly every Park Service area man was on the scene at a respectably remote era of prehistory, even though we grant primacy to his saurian predecessors and the early shell fish and insects at such areas as Dinosaur National Monument and certain fossil bed localities elsewhere. In fact, wherever the Service interprets an area which lies within the extent of the final, or Wisconsin, glaciation, we can be quite sure that man, the other fauna, and the flora all established themselves there nearly simultaneously. And in the areas south of the glaciation man is now suspected of having made his first modest challenge to the ecology in a magnitude of 50,000 years ago, or more, depending upon which interglacial period served to lure him from Asia across the Bering land bridge in pursuit of megafauna, lesser fauna, certain flora, and, ultimately, The American Way of Life.

THE ROLE OF MAN IN NPS AREAS

Considering man's ubiquitous presence in Park areas, it seems strange that The National Park Service has never really tried to address itself to the role of man himself in its areas, if we except those Southwestern areas given to the preservation and interpretation of prehistoric Indian sites. Yet in every major park, in most smaller parks and sites, and in every historical site, man appears to carry on his economy and make his influence felt upon the ecology from the days of the paleo-Indians and the archaic peoples who succeeded these primary populations.

The simple truth--if we may be forgiven adding an extra twist to Judeo-Christian homocentrism--is that man actually has been the most persistent animal ever to attempt to manage the environment he found himself in. These attempts are being magnified in quantum proportions due to recklessly applied technology these last 150 or so years. Ironically in this country and elsewhere, man--the species most dangerous to itself and to other life forms on earth--is devoting himself to maintaining through limited conservation isolated park areas which he has pledged to maintain pristine for his own present and future enjoyment, "forever." And we note this concept originated in our own United States and we are all serving the medium by which the concept is, by law, pledged to survive and flourish.

Accordingly, it is well and good that we accept into the natural and historical environment our best and most dangerous friend, man, his wife and children. Welcome to The National Park System. Let us see how we are coming to know man in total context.

RESEARCH IN DEPTH

At Chaco Canyon the staff of the Chaco Archeological Center is identifying the whole evidence of human presence from the first trace, carried down the ages to the late prehistoric pueblo population, and so into history. At Shenandoah National Park the University of Virginia has produced, under contract, the first part of a multidisciplinary report tracing evidence of man along the Skyline of the Blue Ridge from 6000 B.C. to the mountain folk who were displaced by The National Park Service in 1935, and onward through the days of Camp Hoover, the original presidential hideaway, to the Visitor Center and lodge complex of the present.

At Delaware Water Gap, where man in the Upper Delaware has been investigated more thoroughly the last 80 years than in any other part of the East, the human story goes back demonstrably 11,000 years to the Paleo-Indian users of the same Clovis fluted spear points found in the Shenandoah Valley and elsewhere in the East from Louisiana to Florida and as far north as New Brunswick and the Great Lakes country. This is an artifact type first identified at Clovis, New Mexico, ancient mammoth kill sites, and is spread throughout the Rocky Mountain and Southwest regions to the Pacific coast. At the Gap we are literally on the hinge of the whole swinging story of man in Eastern U.S.A. and it is time to tell the public about it clearly and with authority.

The late Ronald F. Lee, onetime Assistant Director, in his excellently researched booklet on the Antiquities Act of 1906 points out that five significant developments bearing on American archeology, and by subsequent events upon the whole National Park System, took place in 1879. First, in that year Congress authorized the establishment of the Bureau of American Ethnology in the Smithsonian Institution to increase and diffuse knowledge of the American Indian, with John Wesley Powell, original navigator of the Colorado River through the Grand Canyon, as its first Director. The second event was the publication by Frederick W. Putnam, Curator of the Peabody Museum of American Archaeology and Ethnology at Harvard, of his superb seventh volume of the U. S. Geological Survey reports on surveys west of the 100th meridian. This volume inventoried and described many of the outstanding sites of prehistory in the West. Third, in that year the American Association for the Advancement of Science (AAAS) first elected an anthropologist president. This was Lewis Henry Morgan, the nation's first professional anthropologist, and author of the great work on the Iroquois, *Ancient Society*, and the instituter of Section H, devoted to Anthropology, in the annual meetings of AAAS. Eventually the Association established the influential committee which worked for legislation leading to the 1906 Antiquities Act. Fourth, in 1879 a group of interested people led by Professor Otis T. Mason founded the Anthropological Society of Washington which published the American Anthropologist which in turn engendered the American Anthropological Association in 1902, which

[1]National Park Service, Mid-Atlantic Regional Office, Philadelphia.

also provided badly needed support for the Antiquities Act. And lastly, Charles Eliot Norton, one of Harvard's great leaders, led a group that founded the Archaeological Institute of America. In this group of friends was Francis Parkman whose *California and Oregon Trail* had just appeared, and whose interest in the story and work of the American Indian fostered concern of the new Institute with the conservation of American as well as of Classical archeology.

THE PRESSURE OF PUBLIC CONCERN

It was Morgan who through the American Institute of Archaeology drew up a comprehensive plan for exploring and recording important Indian structures in the Southwest, Mexico, Central America and Yucatan, and he chose Adolph F. Bandelier, a native Swiss naturalist and ethnologist from Highland, Illinois, to launch this project. It was Bandelier's report on the desecration by vandalism of the great Pecos ruins of New Mexico in 1880 that aroused wide concern over the danger to the great works of antiquity in the Southwest, and led directly to the first action in Congress toward an antiquities act.

THE ANTIQUITIES ACT AND THE ENGENDERING OF THE NPS

It was actually the saving of two great archeological sites, one now a state park in Ohio and the other the original national monument in the Southwest, that led to the final formulation of the Antiquities Act and the founding of the National Park Service, and consequently the state parks systems of the nation. These sites were Serpent Mound in Adams County, Ohio, purchased by the Peabody Museum of Harvard, and Casa Grande in southern Arizona which became the first federal archeological reservation through the efforts of Frank Hamilton Cushing of the Bureau of American Ethnology of the Smithsonian whose work was in this instance funded by the Hemenway Southwestern Archaeological Expedition whose namesake and mentor, Mrs. Mary Hemenway of Boston had also put up $100,000 to help save Old South Meeting House and preserve it as a historical center, thus wedding architectural and archeological conservation, historical and prehistoric.

Casa Grande, as many of the Park Service family know, was a ruin in 1694 when Jesuit Father Eusebio Kino recorded its four stories and roofless outlying cellular rooms. By 1852 John Russell Bartlett reported Casa Grande reduced to three stories, and the outlying rooms mounds of adobe. By 1889 erosion and vandalism prompted a petition by a committee which included Anna Cabot Lodge, Mary Hemenway, Francis Parkman, Edward Everett Hale, Oliver Wendell Holmes, John Fiske and John Greenleaf Whittier, and on June 22, 1892 President Benjamin Harrison signed an executive order reserving Casa Grande and 480 acres for permanent protection as the first archeological reservation in the United States.

By 1906 the Antiquities Act was finally passed as drafted by Edgar Lee Hewett of The American Institute of Archaeology and presented to Congress by John Fletcher Lacey of the 6th District of Iowa with a companion Senate bill of Senator Thomas H. Patterson of Colorado. The Antiquities Act clearly set the stage for the creation of the National Park Service in 1861 which was to conserve not only natural but also cultural sites and localities and structures, and which was to administer the Antiquities Act.

MAN'S INTEREST IN MAN: A MOTIVATION

This account of the relationship of archeology to the funding of The National Park Service is obviously no digression from the topic of the impact of man on National Park Service areas from prehistory to the present--indeed, it brings the topic squarely into the present and into this very meeting of the First Conference on Scientific Research in The National Parks. The first premise of anthropological investigation is the determination of the cultural factors which cause societies of mankind to formulate customs and laws by which they live. Plainly, in this instance, the motivation of the public by the pressure of informed and scientifically interested scholars and philanthropists moved Congress and the President to act where public interests were at stake. The roots of this action were the scientific inquiries into early man in America.

THE ROLE OF THE ABORIGINES

The tenure of the American aborigines in areas of the National Park System extends a distance into the past at least 40 to 50 times as long as the age of the earliest sites presently established by the Service to honor the advent of European Discovery in America. In this 12 to 20 thousand year continuation of human impact on the land the implications of data based on archeological and ethnological evidence are quite clear. For the forester, the management of land which included the use of fire for the hunt and for slash and burn horticulture indicated a more logical and favorable premise than the mistaken notions of the ecology of fire prior to the 1940's which saw us combatting all fires and allowing underbrush to turn into tinder which led to crown fires and wholesale disaster to forests. The aborigines used fire more aggressively and intelligently on a small scale in managing the environment for their own ends. At least they demonstrated in retrospect that it is better for a few of mankind to exploit all the fauna and flora necessary to his existence than for a multitude of mankind to attempt to invade the environment for recreational purposes while striving to maintain the natural aspect of that land. A contradiction in terms such as this never beset the Indians.

Interestingly, also, the American aborigines were not blessed with that characteristic of the Industrial Age which places greater and more in the context of what is most desirable in life. The premise of the greater the population, the mightier the nation, the more resources exploited the better the life for that population are cultural fallacies which never troubled even the densest settlements in American prehistory. The rhythms of human continuity and those of the faunal and floral resources upon which man depended were closely synchronized and the symbiotic relationships were such that few if any species perished because of man's activities. Even the buffalo jumps and the slaughter of a local herd lured over a cliff were not enough to diminish materially the vast numbers of *Bison antiquus* and *Bison bison* that inhabited the plains of the West, and the kills of mammoth in marshy areas or other natural or artificial traps probably were less of a cause of the vanishing of the megafauna than the diminishing of grasslands in the warm and dry climate that followed the last glaciation.

CONCLUSION

Where America and The National Park Service must now look is to the whole continuum of human use in the areas of parks and consider where the rapidly increasing factor of change in man's prospects due to diminishing natural resources, particularly in fuels, is leading. Obviously

in the next 25 years it is leading to roads on which privately owned automobiles are no longer driven in huge numbers, and which will either be traversed mainly by buses or supplanted by rail lines, preferably monorail, which impinge less on the landscape and provide far more economical transportation. Indeed, it is conceivable that the future may see the systematic obliteration of roads in many instances in order to provide more efficient and less intrusive access to Park areas outside the cities.

By the same token, visitor services structures that were designed to be wildly extravagant in the heating and cooling of their interiors will give way to structures carefully engineered to utilize naturally available energy sources. If the Romans of A.D. 100 could design a bath which was heated comfortably by the sun and air through glassless windows, it is conceivable that modern man could do as well or better as long as he did not profit from the sale of fuel, but rather by the non-employment of it. By a thoughtful, informed, and historically oriented look at present and future problems and opportunities, Park Service management, assisted by its own staff of archeologists, historians and naturalists should be able to increase its efficiency and quality of service to the public.

DISPERSED WINTER RECREATION IN THE CRATER LAKE-DIAMOND LAKE AREA

Kent Downing and Terry Jo Thompson[1]

Winter recreation use of Crater Lake National Park, while relatively low compared with summer visitation, is steadily increasing. Much of the activity is concentrated around Rim Village and the Park Headquarters at the southwest edge of the lake. However, cross-country skiers occasionally travel the entire perimeter of the lake, and snowmobilers are allowed to use a narrow corridor from the north entrance of the park to a viewing point at the north end of the caldera rim. Viewing Crater Lake is recognized as the primary experience for both winter and summer visitors. Future park management goals currently being developed are aimed at enhancing this experience (USDI National Park Service 1976).

Some of the park use originates in the Diamond Lake area located on National Forest land five miles north of the park boundary. Diamond Lake Resort, which operates under special use permit from the Forest Service, is open year-around and attracts visitors for a variety of winter activities. In addition to the lodge, there are rental cabins and motel units; snowshoe, snowmobile and cross-country ski rentals; as well as an innertube sliding hill served by a cable lift.

During the winter skiers and snowmobilers from Diamond Lake travel into the park on the north-entrance road which is closed by snow. Overlapping use between park and surrounding National Forest lands is likely to increase. This winter (1976-77), for example, guided snowmobile rides from Diamond Lake to the rim of Crater Lake will be available. The resort manager has purchased additional rental machines because of their popularity, and the Oregon State Snowmobilers Association has asked the Park Service to open more areas in the park for motorized travel.

RESEARCH ISSUES

This investigation focuses on three issues. First, lack of information about the use. One of the major interests of the managers is to obtain detailed, descriptive information about winter visitors in the Crater Lake-Diamond Lake area. The study, funded by the National Park Service, was undertaken to learn more about who the visitors are and to describe use they make of the park. Additional resources and assistance, provided by the Forest Service and Diamond Lake Resort, made it possible to expand the scope of the study to include the entire winter-use area between Crater Lake and Diamond Lake.

Second, increasing use of the backcountry by cross-country skiers, snowshoers and snowmobilers is causing managers concern about visitor safety. Little is known about the extent to which users penetrate the backcountry and about locations of heaviest use. Avalanches occur in some areas, and dangerous cornices which form along the lake rim can give way beneath unsuspecting visitors.

Third, conflict between skiers and snowmobilers is causing additional problems for managers. Nordic clubs have opposed efforts of snowmobilers who want more areas in the park opened for snowmobiles. There have been suggestions that snowmobile use at the north entrance be eliminated altogether. This issue is representative of a broader problem facing land managers--how to deal effectively with what appears to be a fundamental conflict between advocates of motorized recreation and those who prefer self-propelled forms of transport such as hiking, bicycling, cancoeing and rafting (Knopp and Tyger 1973; Shelby 1976; Stankey 1973).

METHODOLOGY

The principal methods used to collect information about the users and use patterns were: 1) a visitor survey, 2) flights over the area to map use, 3) electric-eye trail counters, and 4) time-lapse photography.

Visitor Survey

Studying dispersed winter recreation use presents many of the same problems encountered in surveying wilderness visitors. Lucas and Oltman (1971) note that ". . . use is relatively light, highly variable in space and time, and users are mobile and often dispersed in hard to reach places." Under these conditions, obtaining an adequate sample size from on-site interviewing is costly.

Although we recognized the problem, we chose to use a short on-site interview in combination with a longer mail questionnaire. This was done for several important reasons. No lists of visitors were available that would enable us to narrow down to the target population--people who use the Crater Lake-Diamond Lake area. Furthermore, we rejected selecting samples from membership lists of nordic or snowmobile clubs on the assumption (which was later supported in the survey) that many users would not be members of such organizations.

To obtain a sample that would reflect a diversity of users and user attitudes, interviews were conducted at five different locations on randomly assigned days during the 10-week period from January 10 through March 21, 1976. Two sites were selected at trails where snowmobiling was prohibited, and three sites where motorized as well as nonmotorized travel was allowed. At three of the sites the interviews were conducted in parking areas with drivers of vehicles. To partially correct for bias which results from interviewing only the drivers, mailback questionnaires were given to all persons, 16 years and older in every fifth vehicle. On-site interviews were completed with 211 different parties. Including two follow-up to nonrespondents, for a total response rate of 83 percent, 201 questionnaires from 176 parties were returned.

Use Patterns

Two methods were used to identify the extent to which people penetrate into the backcountry. Respondents were asked to indicate by reference to a map attached to the questionnaire which trails or areas they had visited on their trip. In addition, three low-level flights were made

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TABLE 1. Characteristics of respondents.

Category	All Respondents (N=201)	User Category: Snowmobilers (N=41)	Skiers (N=95)	Other (N=65)
	%	%	%	%
1. First-time vs. Repeat				
First time visitors	18	15	14	25
Repeat visitors	82	85	16	75
2. Residence				
Southwest Oregon	84	93	81	82
Northwest Oregon	4	2	6	3
Out-of-state	12	5	13	15
3. Length of Stay				
One day	77	40	84	90
Two days	19	48	15	9
Three days or more	4	12	1	1
4. Group Composition				
Alone	6	5	4	8
Couple	27	27	28	27
Teenage & adult groups	30	34	34	22
Family(ies) with children	31	35	20	43
Organization group	6	0	14	0
5. Age of Respondent				
Less than 35	60	34	68	62
35 and over	40	66	32	38
6. Sex				
Female	30	20	34	31
Male	70	80	66	69
7. Education				
H. S. graduate	20	38	6	29
Some college	40	37	36	47
College graduate	18	10	25	14
Post graduate	22	15	33	10

over the area to map recent tracks made by the users. Flights occurred during the afternoon on weekends after users had covered as much area as possible and might be about ready to return to the lodge or parking lot.

Use Levels

Electric-eye trail counters and time-lapse cameras were used to estimate numbers of visitors entering the park and the number traveling selected trails around Diamond Lake. Marcus et al. (1961) reported using a time-lapse camera to study ski-lift use. More recently Marnell (1975) applied time-lapse cameras in studies of floaters on Ozark rivers in Missouri.

RESULTS

During the winter season, Crater Lake National Park and to a lesser extent the Diamond Lake area are primarily day-use areas. Over 75 percent of the people interviewed were on a one-day outing. Most of them (85 percent) live within a 2- or 3-hour drive of the area. Most of the people (82 percent) had been to the area before.

Overall, 10 percent of the respondents visited both Diamond Lake and Crater Lake National Park on the trip. Twenty percent of the people interviewed at Diamond Lake entered the park either on the north entrance trail or at Rim Village, whereas only 2 percent of the people interviewed in the Park near Rim Village visited the Diamond Lake area before they returned home.

Comparison of User Groups

For comparative analysis, respondents were placed into one of three categories: snowmobilers, skiers, or other users (Table 1).[2] Overall there were no significant differences in the proportion of first-time visitors among the groups. There were, however, noticeable differences in length of stay, age and educational background.

As a group, skiers in the sample were younger and have completed more years of formal education. Proportionally fewer were in family groups with children, but 14 percent were along on organized group outings. Only 8 percent belong to nordic or cross-country ski clubs.

[2]Respondents were asked to answer certain sets of questions on the mail questionnaire only if they considered themselves to be snowmobilers, cross-country skiers or snowshoers. Throughout the analysis the skiers and snowshoers were aggregated into one category. Most members of the group were cross-country skiers, and in the interest of brevity, we refer to this category of users in text and tables as "skiers." The analysis assumes that people will correctly identify themselves as snowmobiliers, cross-country skiers or snowshoers even though they may not have participated in the activity on the trip when they were interviewed.

The snowmobilers are older than respondents in the other two groups, and a significantly higher proportion are males. Sixty percent stayed in the area two days or more and concentrated their activities around Diamond Lake. As with the skiers, only 8 percent belong to clubs associated with winter recreation.

Respondents in the "other" category were similar to skiers in age, but more like snowmobilers in educational background, group composition and location of residence. None of the respondents in this category were members of winter sports clubs.

Respondents in each of the categories engaged in diverse activities on the trip (Table 2). Sightseeing and photography which frequently occur in conjunction with other activities were mentioned by a high proportion of the visitors.

Attitudes of Skiers and Snowmobilers

Questionnaire items were included that represent a range of views concerning facility developments, use of national parks by snowmobiles, crowding and encounters with other types of users.

Advocates of nonmotorized use were expected to disagree on many of the questions with those who prefer motorized travel. However, we expected that there would be agreement on some questions and for others, the differences, while statistically significant, would be less extreme, i.e., would range between neutral and agree or disagree. Responses of either type may provide clues to ways of partially integrating these uses.

Furthermore, we hypothesized that many users (particularly repeat visitors) would be aware of which areas provide satisfying experiences and be more likely to visit areas that meet their expectations. Because Diamond Lake is more developed and allows more unrestricted motorized and nonmorotized travel, we expected a higher proportion of the Diamond Lake skiers to favor additional developments and to be more tolerant of snowmobiles than skiers from Crater Lake. The Crater Lake skier may be seeking more of a wilderness type experience.

These hypotheses were generally supported by the data. Snowmobilers and the skiers from both areas tend to favor developments mentioned in the questionnaire (Figure 1). However, Diamond Lake skiers were more favorable toward additional signing and trails than those from Crater Lake.

Respondents tended to be neutral or to disagree slightly with the statement, "I don't like to meet other people along trails" (Figure 2). But if crowding becomes a problem skiers from Crater Lake would be more likely than the Diamond Lake skiers to support a policy of limiting user numbers.[3] Snowmobilers may oppose such action.

Skiers and snowmobilers are strongly polarized in their views concerning the use of snowmobiles in national parks (Figure 3) and meeting each other along trails and in the backcountry (Figure 4). Snowmobilers are not disturbed at meeting skiers, although both Diamond Lake and Crater Lake skiers dislike encountering snowmobilers.

Diamond Lake skiers, as contrasted with those from Crater Lake, tend to be neutral or in slight agreement about trails meeting at points of interest such as the rim of Crater Lake, about trails crossing if they are well-marked, and

[3]The concept of crowding is very complex and difficult to assess by asking only one or two questions of on-site users. For example, Diamond Lake may be too crowded for some users now, and it they have shifted their activities to other areas their view would not be represented by this sample.

FACILITIES AND STATEMENTS	STRONGLY FAVOR	FAVOR	NEUTRAL	DISFAVOR	STRONGLY DISFAVOR	SIGNIFICANCE LEVEL BETWEEN: SNOW-MOBILERS AND SKIERS	SIGNIFICANCE LEVEL BETWEEN: CRATER LAKE AND DIAMOND LAKE SKIERS
WARMING SHELTERS						N.S.	N.S.
MORE TRAIL SIGNS						N.S.	0.05
HAZARDS MARKED						N.S.	N.S.
MORE TRAILS						N.S.	0.05
MORE GROOMED TRAILS						0.01	N.S.
WINTER SAFETY INTERPRETATION						0.01	N.S.
NATURAL HISTORY INTERPRETATION						0.05	N.S.

□ SNOWMOBILERS (N = 30)
○ CROSS-COUNTRY SKIERS (N = 70)
△ CROSS-COUNTRY SKIERS--DIAMOND LAKE LODGE INTERVIEW SITE (N = 25)
▲ CROSS-COUNTRY SKIERS--CRATER LAKE INTERVIEW SITE (N = 45)

FIGURE 1. Attitudes about facilities and developments.

TABLE 2. Participation by activity

Activity	All Respondents (N=201)	Respondent Category: Snowmobilers (N=41)	Skiers (N=95)	Other (N=65)
	%	%	%	%
Sightseeing	70	61	59	92
Photography	49	58	40	57
Cross-country skiing	37	22[a]	67[a]	2
Snowmobiling	18	80[a]	0	6
Innertubing	13	22	7	17
Snowshoeing	6	0	13	0
Tobogganing	4	2	0	1
Ice skating	4	10	1	3

[a]Only 2 out of 3 people classified as "skiers" actually participated as skiers on the trip. Similarly, not all of the snowmobilers snowmobiled. For an explanation of this apparent discrepancy, see footnote 2.

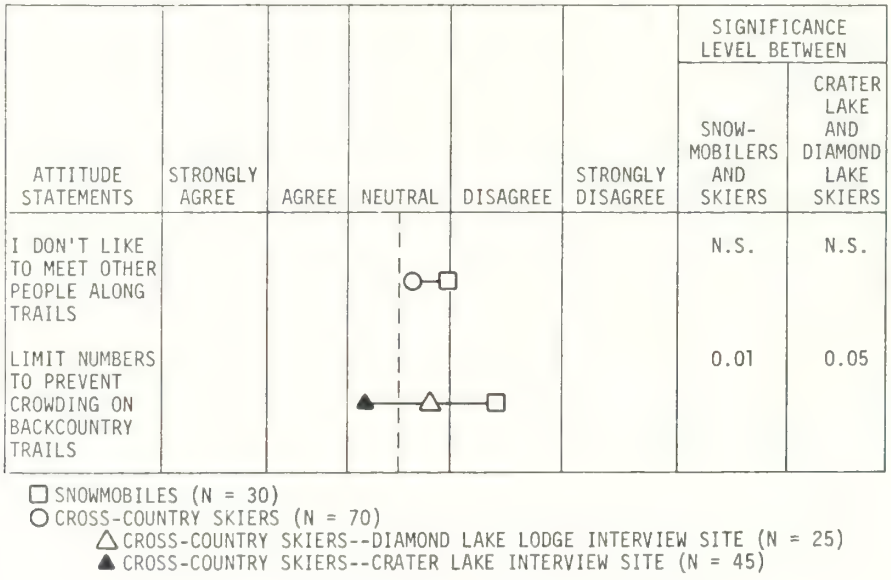

FIGURE 2. Attitudes about crowding and solitude.

sharing parking lots with snowmobilers. These findings suggest that at least around Diamond Lake, sharing or carefully integrating some use areas and trail systems may be possible.

Use Patterns

Aerial surveillance enabled us to map the extent of penetration into backcountry areas, and several areas of high use concentration were easily identified. The flights and use of time-lapse photography led us to conclude that rule violation by snowmobiles entering prohibited areas within Crater Lake National Park occurs far less frequently than initially anticipated.

Users can be counted and differentiated by mode of travel (motorized, nonmotorized) using time-lapsed photography. Identification of individual users, however, is difficult, if not impossible, with the camera placed--as it was in this study--on a platform 15 feet up in a tree. There was no threat to visitors' anonymity in this investigation.

MANAGEMENT IMPLICATIONS

In summary, this study provides managers with an overview of the visitors and their use patterns in the Crater Lake-Diamond Lake area. The largest proportion of use comes from repeat visitors on one-day outings who live within 2 to 3 hours of the area.

Most of the use that overlaps agency boundaries originates from Diamond Lake.

Managers experience problems between motorized and nonmotorized users. The findings suggest that while skiers dislike meeting snowmobiles along back-country trails, Diamond Lake skiers may be more tolerant than those from Crater Lake of occasional encounters where trails and parking areas have been carefully designed and well-marked for both user groups. This greater tolerance may be consistent with their expectations of the development and diversity of activities available at Diamond Lake.

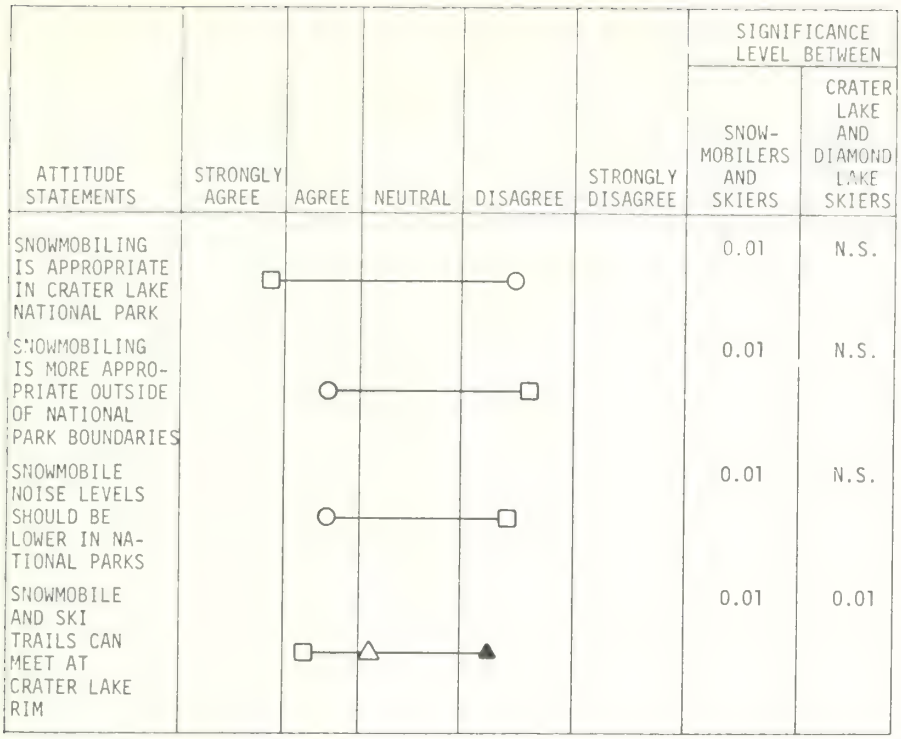

FIGURE 3. Attitudes about use of Crater Lake National Park by snowmobiles.

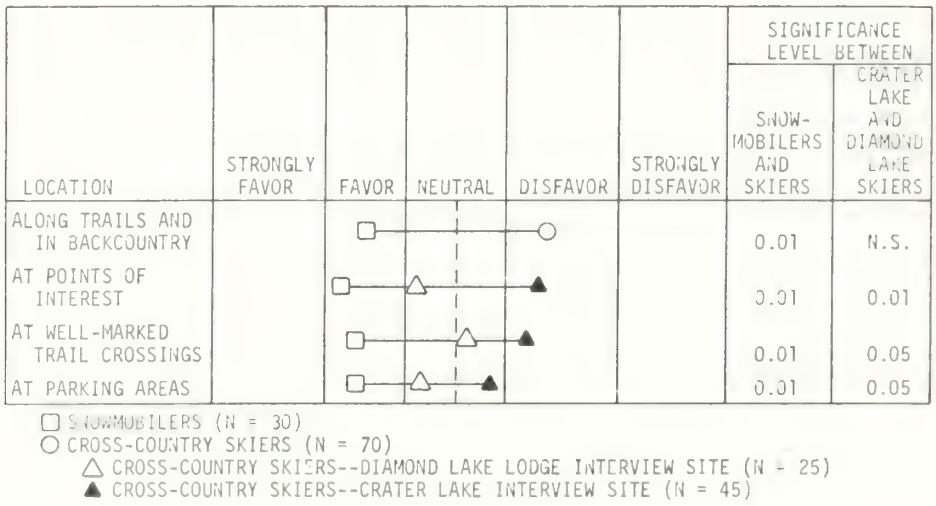

FIGURE 4. Attitudes about meeting other users at different locations.

LITERATURE CITED

KERLINGER, FRED N. and ELAZAR J. PEDHAZUR. 1973. Multiple Regression in Behavioral Research. Holt, Rinehard and Winston, Inc. 534 p.

KNAPP, TIMOTHY B. and JOHN D. TYGER. 1975. A Study of Conflict in Recreational Land Use: Snowmobiling vs. Ski-Touring. Journal of Leisure Research. 5:3:6-17.

LUCAS, ROBERT C. and JERRY L. OLTMAN. 1971. Survey Sampling Wilderness Visitors. Journal of Leisure Research. 3:1:28-43.

MARCUS, LESLIE F., ERNEST M. GOULD, JR., and RICHARD L. BURY. 1961. Measuring the Recreational Use of Natural Forests. Technical Paper 59. USDA Forest Service Pacific Southwest Forest and Range Experiment Station. 26 p.

MARNELL, LEO F. 1975. Use of Time-Lapse Photography for Estimating River Traffic at Ozark National Scenic Riverways. Paper presented at the Workshop for Outdoor Recreation Researchers and Cooperators. Land Between the Lakes, Kentucky. March 9-17. Mimeo. 11 p.

NIE, NORMAN H., C. HADLAI HULL, JEAN G. JENKINS, KARIN STEINBRENNER, and DALE H. BENT. 1975. Statistical Package for the Social Sciences. 2nd Ed. McGraw-Hill. 675 p.

SHELBY, BO and JOYCE M. NIELSEN. 1976. Motors and Oars in the Grand Canyon: River Contact Study Final Report, Part II. Human Ecology Services, Inc., Boulder, Colorado. 57 p.

STANKEY, GEORGE H. 1973. Visitor Perception of Wilderness Recreation Carrying Capacity. USDA Forest Service Research Paper INT-142. Inter-mountain Forest and Range Experiment Station. Ogden, Utah. 61 p.

U.S.D.I. NATIONAL PARK SERVICE. 1976. General Management Plan: Crater Lake National Park. Revised Draft. Denver Service Center. 39 p.

ECONOMIC IMPACT OF PROPOSED KLONDIKE GOLD RUSH NATIONAL HISTORIC PARK ON SKAGWAY, ALASKA

Ken L. Casavant and James C. Barron[1]

INTRODUCTION

The activities of the United States National Park Service have strong interaction with localities in and around park locations. The success of the National Park Service and their park managers in maximizing the benefits accruing to local areas while minimizing the negative impact will be reflected in the attitude of the indigenous citizens of the region towards the National Park Service and the national parks. A receptive and supportive local populace will be conducive to a good recreational experience on the part of park visitors, an acknowledged goal of park managers.

The proposed Klondike Gold Rush National Historic Park offers a unique opportunity to undertake a systematic and continuing economic analysis of the impacts of a national park on the local community--in this case, Skagway, Alaska. The understanding gained from such a study could be applied to the analysis of impacts from other proposals for new parks or changes in existing parks. Park managers could mitigate local problems, as identified in the analysis, and increase the possibility that park activities do not prove to be a net cost to the local area.

The overall purpose of this paper is to examine the interaction between the proposed Klondike Gold Rush National Historic Park and the people and economy of Skagway, Alaska. Specific objectives are to (1) develop a framework for examining economic impacts and (2) test this framework on the proposed park and its interaction with Skagway. Finally, some conclusions about the probable impact of the park on Skagway and benefits of longitudinal study of the area will be offered.

ANALYTICAL FRAMEWORK

The analytical framework for considering the economic impacts on Skagway from the proposed park rests on economic base theory. This formulation of a model of a regional economy consists of an export base sector and a local service sector. The export base consists of those economic activities which "export" goods or services to satisfy demand from outside the region. Local service is the economic activity required to maintain or "service" the export base.

As will be discussed in more detail later, Skagway has a relatively simple economy. The export base consists of tourist services and transportation services, with the latter being much larger than the former. No physical products originate and are exported from Skagway, only services. Local service consists of retail establishments providing food, clothing, hardware and utilities. Even much of the retail sector is part of the export base in that it provides retail services to tourists.

Use of economic base theory as the framework for analysis allows those specific variables to be identified that are susceptible to change due to creation of the park. Employment patterns, tourism and retail sales, patterns of private and public investment, public service financing, and land use are the variables investigated in this paper.

SKAGWAY'S ECONOMY

Transportation was and is the raison d'etre of Skagway. It also serves to delineate any potential impacts of the proposed national park. The historical reason for creation of Skagway, and the associated death of Dyea, was to provide transportation services to the 1893 Gold Rush participants via the White Pass and later the White Pass and Yukon Route (the railroad in Skagway). This reliance on transportation has even increased in modern times.

The import sector of the local economy is also totally dependent on transportation. All food, clothing, and most building supplies are brought into Skagway. Even cultural events and television programming have been delayed or canceled due to the failure of the transportation system to provide needed services.

The two principal export commodities of the local economy of Skagway are the services of a transportation mode (the White Pass) and tourism. Both are obviously dependent upon or could be defined as transportation. Without the existence of transportation as an export base, Skagway, as we know it today, would cease to exist.

THE PEOPLE

Skagway's economy is described in Table 1. Two out of three jobs are in the transportation sector and, as suggested above, most of the jobs in trade and service are directly related to export of tourist services. The only other significant sector is government which includes the city of Skagway, the local school, two or three custom inspectors, and a representative of the Alaska marine highway. This heavy dependence on transportation has resulted in a creation of institutions to handle transport-related activity long before any thought was given to creation of a national park. Hence, increased tourism has had relatively little impact on the basic transportation sector. The overall population was 675 in 1970. Over the years it has been a relatively stable community, influenced mainly by the outside forces of tourism and ore shipments.

About half the housing units are owner-occupied and the other half renter-occupied. The housing situation is very tight for several reasons. New construction is quite expensive because labor as well as materials must be imported. Seasonal employment related to tourism provides a strong demand for only four months of the year. Thus, there is little incentive for investors to build rental units which might be full only one-third of the year.

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TABLE 1. Estimated employment in Skagway, July 1973.

Sector	Employment
Construction	3
Finance	4
Government	38
Manufacturing/processing	4
Service	25
Trade	42
Transportation/communications	215
Total	331

Source: State of Alaska, Department of Economic Development, "A Community Profile: Skagway, Alaska," July 1973.

PRIVATE SECTOR

Railroad[2]

The private sector of Skagway is so highly dependent on the White Pass and Yukon Route that it has been characterized in the past as a "Railroad Town" or "Company Town." Approximately 60-65 percent of the total employment in the city was directly dependent on the White Pass in 1962-73. Additionally, the railroad owns most of the industrial land in Skagway as well as once having owned the only hospital in town.

The railroad is really a multi-model transportation company with trucks and ocean-going ships in conjunction with the railroad function. The economic health of the White Pass, certainly an integral factor underlying the economy, is strong. Retained earnings trend and the ratio of net earnings to gross revenues suggest that the present position is one of a capital-intensive, efficient and productive railroad that has the ability to generate any needed capital investment in the future.

Nonpassenger movements generate 89 percent of revenue for the railroad. The largest single freight movement, containerized ore concentrates, is expected to continue to be the strongest revenue source for the railroad.

The Klondike Gold Rush National Historic Park is expected to encourage more visitors to come to Skagway. These visitors may be passengers for the railroad or could travel the coming Carcross Highway. The railroad presently receives 11 percent of annual revenues from passenger traffic and is considered a potential growth area by management. New investments in passenger cars and rolling stock are now under consideration. Projections by the White Pass without the park indicate up to 15 percent annual growth.

[2]For a detailed history and economic analysis of the financial structure and future of the White Pass and Yukon Route see Barron, James C. and Kenneth L. Casavant, Economic Impact of Proposed Klondike Gold Rush National Historic Park on Skagway, Alaska, A report to the National Park Service, December 1974.

Tourism

The Alaska Marine Highway system has greatly increased the impact of tourism in the area by allowing passengers to disembark at ports of call and board later ferries. To identify the probable impacts of the national park it is useful to examine the type of visitor to the area. A general breakdown of visitors might be as follows: (1) those who come to Skagway as a destination point; (2) those for whom Skagway is a transfer point on the way to somewhere else; and (3) those who are hikers or backpackers.

The first group arrive by ferry and cruise ship, are in middle-income levels or above, and are generally middle-aged and older with many retired people. Those tourists using Skagway as a transfer point are usually automobile travelers or bus and train passengers. These are more usually family groups, middle-aged or older, and with relatively large incomes.

The final group of hikers and backpackers differ from the first two in that they are younger, in a much lower income category, and make only small amounts of purchases from local business.

The source of these visitors is via the Alaska Marine Highway and cruise ships operating in the Inland Passage. The seasonal capacity of cruise ships has significantly increased over time. It is these passengers who are presently utilizing the White Pass, particularly the Bennett Turn-around movement.

The Alaska Marine Highway allows tourists to remain in Skagway between ferry runs, thus increasing tourist trade and developing a more stable tourist industry. No highway access to Skagway presently exists, but a road linking Skagway to Carcross and Whitehorse is under construction and scheduled for completion within one or two years.

Retail Sales

The Skagway business community is almost entirely made up of retail sales of goods and services. Sales in 1973 were about $3.2 million. Direct sales to tourists are about 30 percent of the total, but indirect tourist-related sales increase to about 40 percent the share of retail sales attributable to the tourist industry. Most of the rest are, of course, accounted for by people who are employed in the other export sector--transportation services.

Summary

It should be stated that, in the private sector, transportation is the medium by which the impacts of the national park will be felt. Changes in tourist traveling through the areas; changes in level of merchandise carried through the physical distribution system; changes in the financial picture of the transportation firms themselves; and even some changes in the dependency of the local economy on the White Pass for the economic livelihood of the region; all of these reflect the fact that transportation and Skagway as an economic entity are inseparable.

PUBLIC SECTOR

The city government of Skagway plays a more important economic role for its citizens than do many other cities of the same size due to the relative inaccessibility of Skagway and its heavy dependence on outside sources of supply for both goods and services. Thus, the city government performs some functions, such as operating a

health center and serving as mortician, which it might not otherwise do.

The city of Skagway depends primarily upon the property tax (46 percent) for its revenue. The retail sales tax of 3 percent also adds another 18 percent of revenues. Any major change that affects those revenue sources will affect the public sector of the community.

ANALYSIS OF IMPACTS[3]

The benefits and costs of the proposed Klondike Gold Rush National Historic Park fall into various sectors of the export-base analytical model. The following impacts and distribution to be those of interest to park managers as well as the citizens of Skagway.

Employment. Both short-run and long-run employment impacts will be felt. Management and restoration of the historical buildings in the park will create 18 permanent and 19 seasonal jobs in the short run and about a dozen in the long run. Both of these should be considered quite small in impact on Skagway, particularly since many of these could be filled by permanent residents of Skagway.

Railroad. The White Pass and Yukon Route will be affected both positively and negatively by the park. The railroad may lose some passenger traffic from automobile travelers, but none of their other sales volume appears threatened. Passenger traffic may increase because of the park's drawing power, thus causing a zero net effect on the railroad.

Tourism. With or without the park and highway the seasonal flow of tourists will continue to be uneven. Normal growth in Alaska tourism is expected to bring an additional 5 percent annually to Skagway. The park may attract an additional 2-3 percent. Severe constraints in hotel rooms, housing and docking facilities place limits on the physical capacity to handle many more tourists.

Property values. Land is limited, but much unused space is available to accommodate growth over time. Demand for housing and new business development will push values upward, but sharp or large increases are not expected unless property owners hold back for large speculative gains. New housing built in reaction to the coming park should realize a good return.

Public sector. Some changes in the tax structure will occur as the park acquires some property. Reductions in property taxes as land is removed from rolls will be offset to some extent as new development takes place. Public service demands will increase, especially for fire protection and possibly for new capital outlays, i.e., sewage treatment.

Others. Little immediate impact on forest production, recreation, and land use will be realized. Any changes in these areas need not be abrupt, but can be spaced over time.

The benefits and costs of the park will be widely and unequally distributed. Some direct benefits to Skagway residents will result from increased property value and an expansion in the range of services available. Some sales of business property have already taken place. But, there will also be costs--higher public service costs for fire and police protection, congestion and dust from more cars, and some loss in local flexibility and control over the affairs of the town. This "sense of invasion" may be accentuated if outside investors, such as tour companies, capture much of the financial benefits if they commit investment capital for development in Skagway.

FUTURE IMPLICATIONS

The projected impacts of the Klondike Gold Rush National Historic Park offer specific managerial direction to management personnel of the National Park Service. Identification of the economic structure of Skagway allows probable conflict sectors to be watched by sensitive park managers. This monitoring of impacts can cause potential conflicts not to materialize or all existing ones to be minimized.

In a broader sense interaction of this park activity and the small community of Skagway can provide information, both managerial and interpretive, that will be useful as new parks are created or older ones modified. A continuing study of the Skagway experience would allow a test of the export base analytical approach used in this paper as well as an analysis of the underlying causes and effects of the variables outlined in this paper.

[3]For a detailed analysis of magnitude of impacts to be expected from the creation of a park, see Barron and Casavant as in footnote 2.

STRATEGIES FOR THE ASSESSMENT OF SOCIAL-PSYCHOLOGICAL CARRYING CAPACITIES OF WHITEWATER RIVERS: A COMPARATIVE ANALYSIS

Richard M. Schreyer[1] and Joseph W. Roggenbuck[2]

Exponentially increasing use rates for certain wildland recreation activities have promoted concern on the part of resource managers that use levels may be causing environmental damage or reducing the satisfactions of users. The concept of carrying capacity has been used in recreation as a theoretical indication of an upper limit in allowable use levels.

Whitewater river running on federally administered lands in the western United States is an example of this pattern. Recreational use of various rivers has grown rapidly in the last decade, with 50 percent annual increases being common (Roggenbuck 1975). In response to such rapid changes, many managers have responded by setting maximum seasonal use limits or "carrying capacities" for the rivers. However, most such estimates are based more on an educated guess than on hard data (Schreyer 1976). This lack of firm criteria has prompted the Director of the National Park Service to issue a policy directive freezing use levels on rivers under National Park Service jurisdiction in the Colorado River drainage until "scientific evidence" can justify a change either up or down (Everhardt 1974). Thus, the National Park Service has formally committed itself to the determination of "carrying capacities" for this type of recreation.

We propose in this paper that the determination of carrying capacity is dependent upon the formal specification of parameters for utilizing input from the recreational resource users. Given the diversity of users of a recreational resource, it may be necessary to identify which experience or users will be considered in such a determination.

PROBLEMS OF CARRYING CAPACITY ASSESSMENT

Lime and Stankey (1971) identify three components to the determination of carrying capacity: management objectives, ecological impacts, and visitor attitudes and satisfaction. We believe the latter component to be the most critical to the determinations at hand. While we will not address the first two components in depth, we will briefly examine them in light of the last component. Management objectives related to recreation are not likely to be directed toward the limitation of visitors for a particular activity. Such objectives are most often couched in the broadest possible contexts such as "for the benefit and enjoyment of the people." Perhaps the most specific and managerially useful statement of objectives is the Wilderness Act (P. L. 88-557), which declares that wilderness should provide "outstanding opportunities for solitude or a primitive and unconfined type of recreation." This statement specifies a certain type of recreational experience to be provided, focuses on the visitor satisfaction component of carrying capacity, and suggests certain criteria to be used in actual determinations of use limits.

Where multiple uses are pursued, objectives may provide for the protection of a flow of resources with which recreational use levels can interfere. The principal focus of this paper is National Park Service recreation, however, where concerns tend to fall more on preservation of environments. Ecological impacts may therefore appear to be limiting. However, in the case of whitewater river recreation, much of the previous work on impacts to the environment has indicated that recreational use does not have a major impact except in areas of concentrated use, such as campsites, and that compared with other human influences, such as dams, these impacts are minimal (Dolan et al. 1974; West 1976). While absolute impacts may therefore not be sufficient to establish a limit to use, the perception that areas are being impacted may be an important consideration. This again shifts the emphasis to the visitor attitude component.

BEHAVIORAL DIMENSIONS OF CARRYING CAPACITY

The visitor attitude component of carrying capacity implies that the users of a resource may perceive it to be too crowded for their personal satisfaction. This must be viewed in a broader context to understand the factors involved. Recreation as a behavioral phenomenon may be considered an experience in which individuals engage in a particular activity with the expectation that certain rewards (i.e., excitement, solitude, friendship, status, etc.) associated with their perception of that activity will be obtained (Driver and Tocher 1970; Knopf and Driver 1973). Satisfaction in participation is therefore a function of the fulfillment of these expectations. These assumptions are in line with expectancy theory in social psychology (Roggenbuck 1975).

Recreational engagements are seen to be complex. Certain kinds of participation may be associated with a variety of expectations (Knopf 1972; Knopf et al. 1973), and, therefore, a variety of satisfactions may also be derived (Hendee 1974). Given diversity in individual need states, information resources, living environments, etc., it is assumed that different individuals may participate in the same activity for different reasons, though the ability of a particular kind of experience to provide certain satisfactions may tend to make it more highly associated with certain specific outcomes. Not all expectations are density-dependent (i.e., subject to disruption through crowding). Further, those that are may be differentially sensitive. The desire for solitude is much more likely to result in lower threshold of crowding than the desire to experience nature, even though both may be considered as being density-dependent.

Given the above, the ability to identify carrying capacities based upon user perceptions involves the specification, in terms of

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managerial objectives, of density-dependent expectations to be provided by the particular recreational opportunity. User input, given the diversity in potential expectations which may be brought to the site, consequently, depends upon the identification of that segment of the population whose perceptions reflect those key expectations. The perceptions of crowding would therefore be geared to the specific expectations sought. This line of argument also assumes that taking an average of all users will not be productive, since the multiple and conflicting expectations will tend to cancel out one another, making an effective determination of crowding difficult, if not impossible.

There are three ways in which this diversity may be approached:

1) A number of groupings of persons using the whitewater resource may already exist: commercial vs. private vs. educational users; experienced vs. inexperienced users; users on one-day trips vs. overnight users, etc. The various experience expectations of these groups may be compared for their differing perceptions of crowding.

2) The expectations themselves may be used. Regardless of any real world groupings, it may be possible to identify users who are high in the specified experience expectations. Responses to crowding of these persons may then be examined.

3) Some formally established criterion of consistency with recreational experience objectives may be used. Stankey (1971, 1972) has suggested using an attitude scale to measure agreement with the provisions of the Wilderness Act as a means to identify appropriate perceptions of management issues, including crowding. Persons closest to the values expressed in the Wilderness Act are assumed to have expectations which will reflect the values for which the opportunity was created. Such an approach has the advantage of having an institutional foundation for its specification of criteria.

The research reported here was designed to examine the comparative differentiation in perceptions of crowding of users of a given activity. Specifically, we hypothesized:

1) Different identifiable subgroups of participants in a whitewater river recreation will differ significantly in the importance of experience expectations concerning that activity.

2) Users who differ in the intensity of specific experience expectations will differ significantly in their perceptions of crowding.

3) Different experience expectations will be differentially associated with perceptions of crowding. That is, for some expectations, the presence of other individuals will be a more important factor than for others.

4) Persons scoring differentially on a wilderness-attitude scale will differ significantly in the relative importance of experience expectations.

5) Because of the differential importance of their expectations, persons who score differently on a wilderness-attitude scale also will differ significantly in their perceptions of crowding.

THE STUDY

Dinosaur National Monument, located on the border between Utah and Colorado, was used as the site for the study (Schreyer et al. 1976). Two major rivers, the Green and the Yampa, flow through the monument, join at Echo Park, and exit the monument at Split Mountain. Both rivers have recreational float trip use. The monument has several features which make it conducive for this study. A number of different kinds of groups may be identified, principally commercial, private, and educational users, and day and overnight users. In response to rapid increases in use levels, monument officials set a maximum use level of 17,000 visits in 1972, which has subsequently been frozen by the Everhardt directive until research may be generated. Finally, the area represents an easily studied unit, with accurate records on expected use rates and a single point of termination for all boat trips--Split Mountain Campground.

During the summer of 1975, a questionnaire was distributed to river recreationists as they disembarked from their trips at the Split Mountain boat ramp. The questionnaires were to be completed upon returning home and mailed back in a postage-paid envelope which was provided. The sample was a systematic random sample stratified by day vs. overnight user. Three four-day sampling clusters were employed for each of the four major use months of May, June, July, and August. A total of 1,141 questionnaires were distributed. Two follow-ups yielded 854 usable returns, representing a 76 percent response rate.

The questionnaire asked respondents' attitudes concerning management strategies for the monument, perceptions and evaluations of encounters with others on the trip, a wilderness-attitude scale, a scale measuring experience expectations, and certain background and trip-related variables. The wilderness-attitude scale consisted of 27 statements pertaining to perceived appropriate uses, values, and benefits of wilderness areas to which respondents were asked to indicate agreement or disagreement. The final list evolved from more than 100 statements through expert panel selection and pretesting. Seventeen items ultimately were used in constructing an index in which respondents were given a numerical score based upon their degree of agreement with the letter and intent of the Wilderness Act. The process is described in detail elsewhere (Schreyer et al. 1976). After scores were assigned, the recreationists were divided into three groups, labeled as Low Wildernists (LW), Moderate Wildernists (MW), and High Wildernists (HW). The middle group had approximately half of those receiving scores, while the two extreme groups had approximately a quarter each.

The experience expectations were developed in a 38-item scale patterned after scales developed by Driver (1976a, 1976b). Respondents were asked to indicate the relative importance of certain kinds of outcomes or experiences from their river trip. Nine classes of expectations were hypothesized and at least three items dealt with each expectation. Factor analysis yielded seven conceptually useful experience expectation categories (Roggenbuck 1975). Indices for the various expectations were created, with the number of items ranging from three to seven. Reliability was checked through inter-item

TABLE 1. Classes of expectations for the river experience.

Motive Category	Total Sample			Day Users		Overnight Users		
	Average Score	Standard Deviation	Sample Number	Average Score	Number	Average Score	Number	T[1]
Learning About Nature	4.31	1.03	848	4.06	185	4.33	663	-0.74
Stress Release/Solitude	3.56	1.27	845	3.19	186	3.67	659	-4.57*
Autonomy/Achievement	2.81	1.13	846	2.33	186	295	660	-6.74*
Affiliation	3.36	1.31	846	2.95	185	3.48	661	-4.94*
Self-Awareness	2.66	1.45	843	2.14	184	2.80	659	-5.51*
Action/Excitement	4.91	0.90	849	4.91	187	4.91	662	0.10
Status	2.33	1.15	838	2.42	185	2.30	653	1.26

[1]The 't' value is a statistic used to test the significance of difference of the means of two groups by the student's T-test. An asterisk (*) by the value indicates that the difference is significant at the .05 level of probability (one chance in 20 that the difference between the scores on samples from the two groups would be this large by sheer chance).

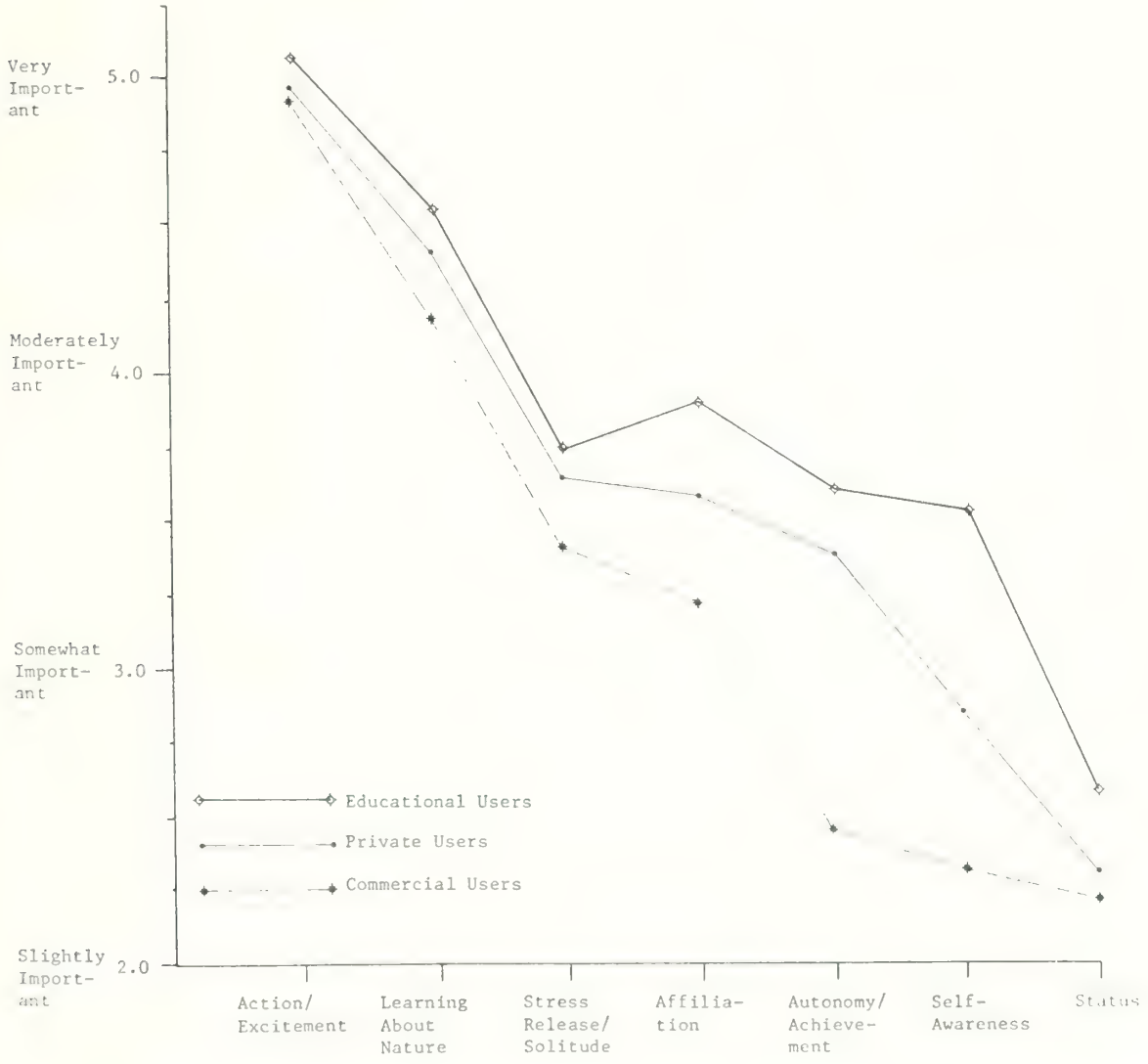

FIGURE 1. Differences among commercial, private, and educational groups on the seven experience expectations.

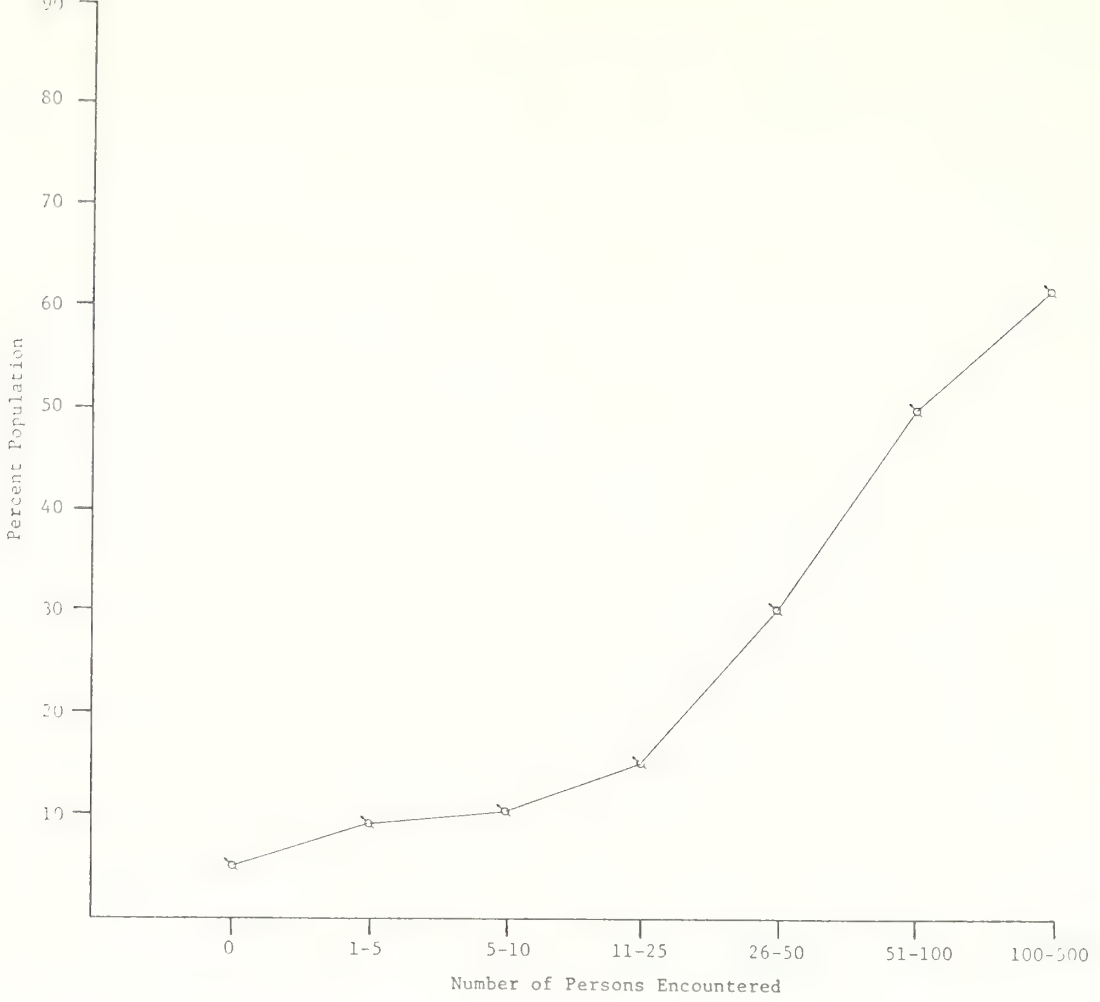

FIGURE 2. Responses of total population to numbers seen in terms of percent claiming they had seen somewhat or far too many people.

correlation. An alpha coefficient (Nunnally 1967) of .80 was maintained for all indices except status, which received a .68. The seven categories of experience expectations were Learning About Nature. Action/Excitement, Stress Release/Solitude, Affiliation, Autonomy/Achievement (the feeling that one had personally accomplished something through the experience), Self-Awareness (use of the experience as a means to look inside oneself, to be introspective, to become more aware of one's values), and Status.

RESULTS

Group Expectations

Table 1 shows average scores for the sample on the seven categories of experience expectation. Possible scores ranged from a "1" (not at all important) to "6" (of utmost importance). The range in importance is considerable. Action/Excitement is the most important expectation, with Learning About Nature second, while Stress Release/Solitude is a distant third. Of least importance is the Status expectation, though this could easily be attributed to response bias for social desirability.

An examination of population subgroups reveals differences in the degree of importance of the various expectations. Table 1 also shows average scores for day users and for users on overnight trips. Overnight users score significantly higher in the importance of Stress Release/Solitude, Autonomy/Achievement, Affiliation, and Self-Awareness. No significant difference was found in the two most important expectations of Action/Excitement and Learning About Nature. These two values appear uniformly important for both populations.

Figure 1 shows a graphic representation of the experience expectations for commercial, private, and educational groups. The groups differ at the .01 level of significance on all expectations except the most important one, Action/Excitement. The average group scores on each expectation scale are in a decreasing order of rated importance from educational to private to commercial users. The most dramatic magnitude of difference is in the Autonomy/Achievement category. It is conceivable that the results indicate a tendency for persons to rate values more strongly if their degree of involvement in the experience is greater, even though the relative order of importance is the same. Persons on educational trips tend to be more actively involved in aspects of the experience, such as rowing, cooking, chores, etc. (and, we might add, are also more likely socialized in the imporatnce and value of their experience), than are private users, who in turn are more actively engaged than commercial-trip passengers. The intensity of difference on the Autonomy/Achievement scale tends to support this conjecture. Nevertheless, existing groups are seen to differ significantly in the rated intensities of differing experience expectations.

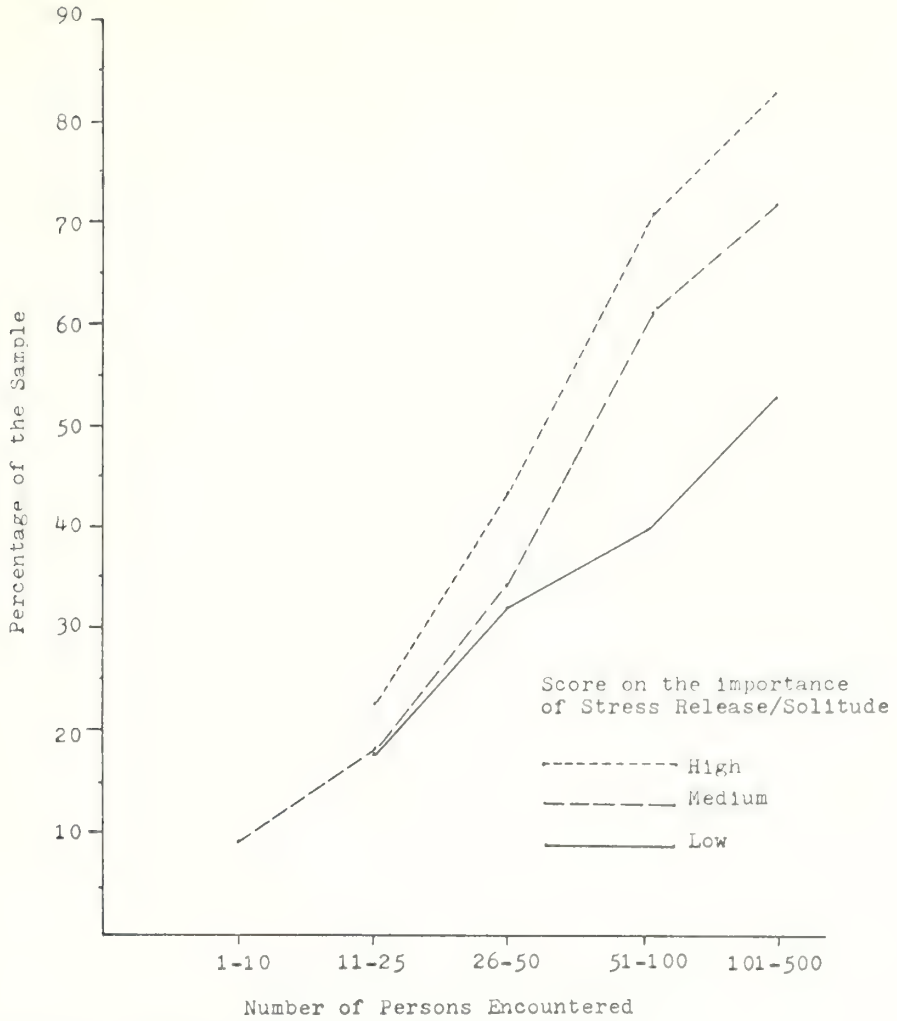

FIGURE 3. Perceptions of crowding for river recreationists with differing scores for Stress Release/Solitude.

Perceptions of Crowding

Individuals were asked to estimate the numbers of persons they had encountered during the trip and to express whether or not they had felt they had seen too many persons on the trip. Figure 2 shows the percentage of users indicating they felt they had seen somewhat or far too many users on the trip for various levels of encounter. As encounters rise, so do perceptions of crowding, as would be expected. However, crowding may be viewed in a number of ways. An overall average of users showed 50 percent indicating they had seen the right number of users, while approximately a third felt they had seen too many. Figure 2 presents information which may be more complex, but in the long run more useful. Our intent is to show that more information may be obtained by considering the influence of the differing expectations on perceptions of crowding.

Not all expectations are highly density dependent. For instance, Action/Excitement would likely have little that would be disrupted by the presence of others (and often just the opposite--others would enhance the fun). However, those that may be sensitive could be an important part of the experience. Two expectations are shown in Figures 3 and 4 in their relationship to crowding. In each case, expectation scores of respondents were assigned high, medium, and low categories in a manner similar to that of the wilderness scale. Figure 3 shows that persons high in Stress Release/Solitude are more likely to feel crowded at each level of encounter and the gap widens as levels increase. Figure 4 shows a similar relationship based on scores on Self-Awareness, though the increased widening of the gap is not quite as pronounced.

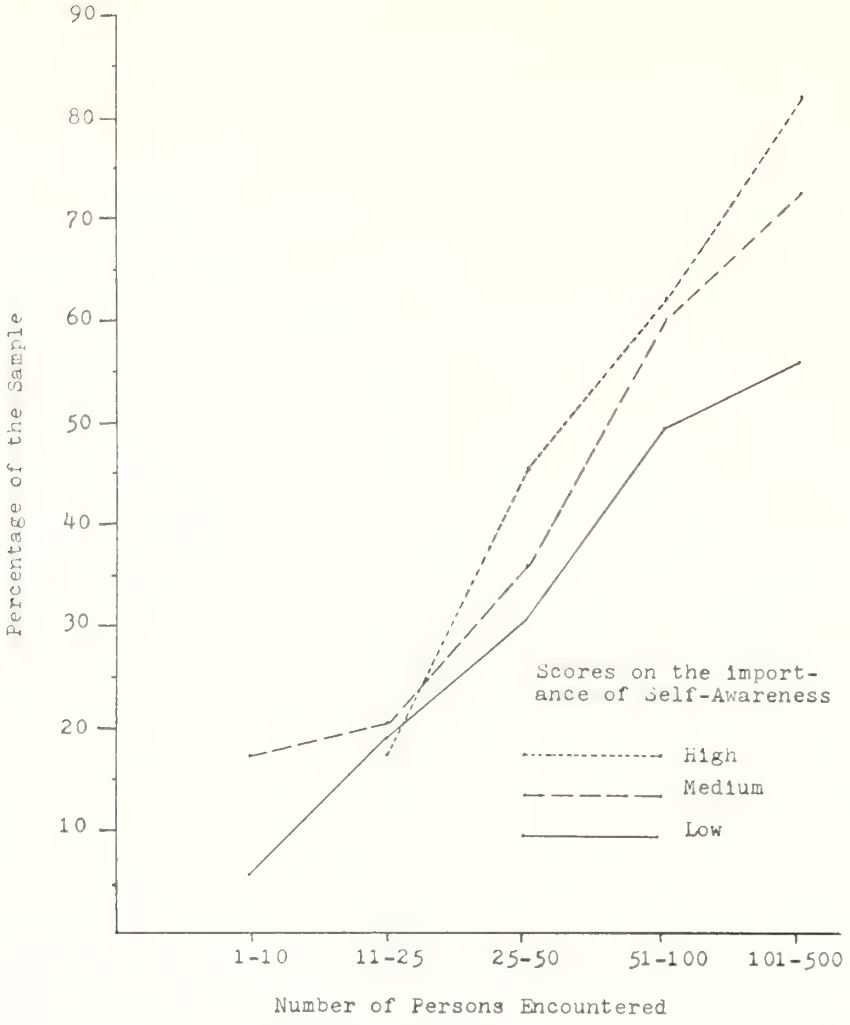

FIGURE 4. Perceptions of crowding for river recreationist with differing scores for Self-Awareness.

Wilderness Attitude

The experience expectation scores of the three wilderness categories are shown in Figure 5. A number of differences is significant and in directions which make conceptual sense. High Wildernists are significantly higher in Learning About Nature (.001 level of significance) and lower in Action/Excitement (.05 level of significance) than the other categories. While the magnitude of the difference on the latter is not great, it is important to note that of all comparisons of various river user groups on the Action/Excitement scale, this is the only comparison for which any difference was noted. Further, a comparison of scores on the two expectations shows that while Learning About Nature is nearly as important as Action/Excitement for the HW's, it is considerably less important for the other two groups.

The Affiliation scores of the three wilderness categories differed, and the Stress Release/Solitude scores just missed differing, at the .05 level of significance. It is interesting to note that the relative ordering of the three wilderness classes is reversed, with the HW group being high on Stress Release/Solitude and low on Affiliation, while the LW group registers just the opposite. Further, the score for the LW group is higher for Affiliation than for Stress Release/Solitude, while the HW's show a higher absolute score for Stress Release/Solitude than for Affiliation. Thus, those who are strong on wilderness values appear to place a greater emphasis on solitude and lessened emphasis on social interaction.

Finally, the wilderness categories were examined for their differing responses to crowding. Results are shown in Figure 6. The HW group consistently registers a higher degree of perceived crowding at each level of encounter. At the highest levels of encounter, nearly 86 percent of this group felt they had seen too many people.

DISCUSSION AND CONCLUSIONS

A profile of relative importance of differing experience expectations has been shown for recreational whitewater river float trips on the Green

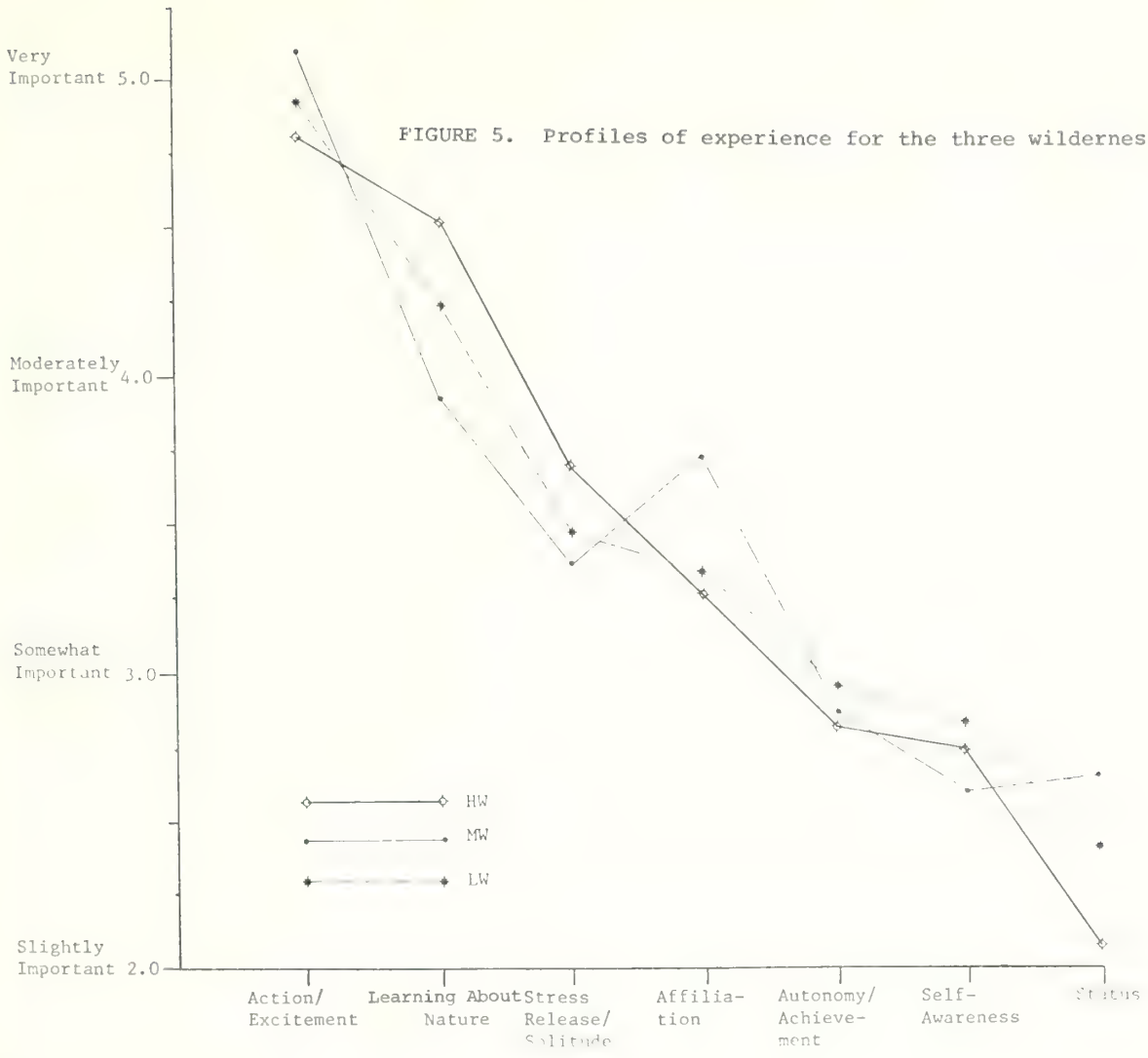

FIGURE 5. Profiles of experience for the three wilderness categories.

and Yampa Rivers in Dinosaur National Monument. When differing existing groups such as day vs. overnight users or commercial vs. private vs. educational users were examined, significant differences in expectation scores emerged. It may be remarked that while the differences were significant in a statistical sense, absolute magnitudes were not great, and in fact the ordering of relative importance of the expectations tended to remain the same. However, it should be noted that we are examining expectations for users of the same activity--whitewater river running, in essentially the same environment. It is not unreasonable to expect, therefore, that a characteristic profile of the activity is likely to remain stable. Thus, the differences among the various groups may take on added significance when viewed as being differing perceptions on essentially the same activity.

When users were compared on their scores on the experience expectations, there were differing sensitivities to crowding recorded. Those strong in Stress Release/Solitude and Self-Awareness showed the greatest sensitivity to crowding. In other analyses, scores on Learning About Nature showed a similar relationship, though it was not as strongly pronounced. When users were compared on Action/Excitement, no such patterns emerged. Thus, different expectations had different responses to crowding.

An examination of recreationists based on their attitudes toward wilderness indicated that the differing attitudes were related to differing experience expectations for their trip. Further, those who were strong on such wilderness values were the most sensitive to crowding at the various levels of encounter.

All of the hypothesized relationships were supported by the data. The implications for assessments of crowding, particularly as they are couched in terms of "carrying capacity," suggest a greater degree of attention to the diversity of expectations for experience which may exist within a given resource. The assertion that 50 percent of all users feel they encounter the right number of persons is considerably different from the perception that 86 percent of High Wildernists feel too crowded in certain situations. They may become particularly important if specific legal mandates, such as the Wilderness Act, are applied to recreational experiences in such environments. Further, if differing sensitivities to crowding are seen to be a function of certain experience expectations and the ability of the presence of others to prevent the satisfactory attainment of those desired experiences, then the determination of crowding for any resource unit must be a function of the objectives for specific experiences provided for by management. If primary management objectives center around experiences that are relatively density-independent, then there may be no justification for the establishment of social psychological carrying capacities at use levels anywhere near current use levels. Conversely, if highly sensitive experiences are identified as

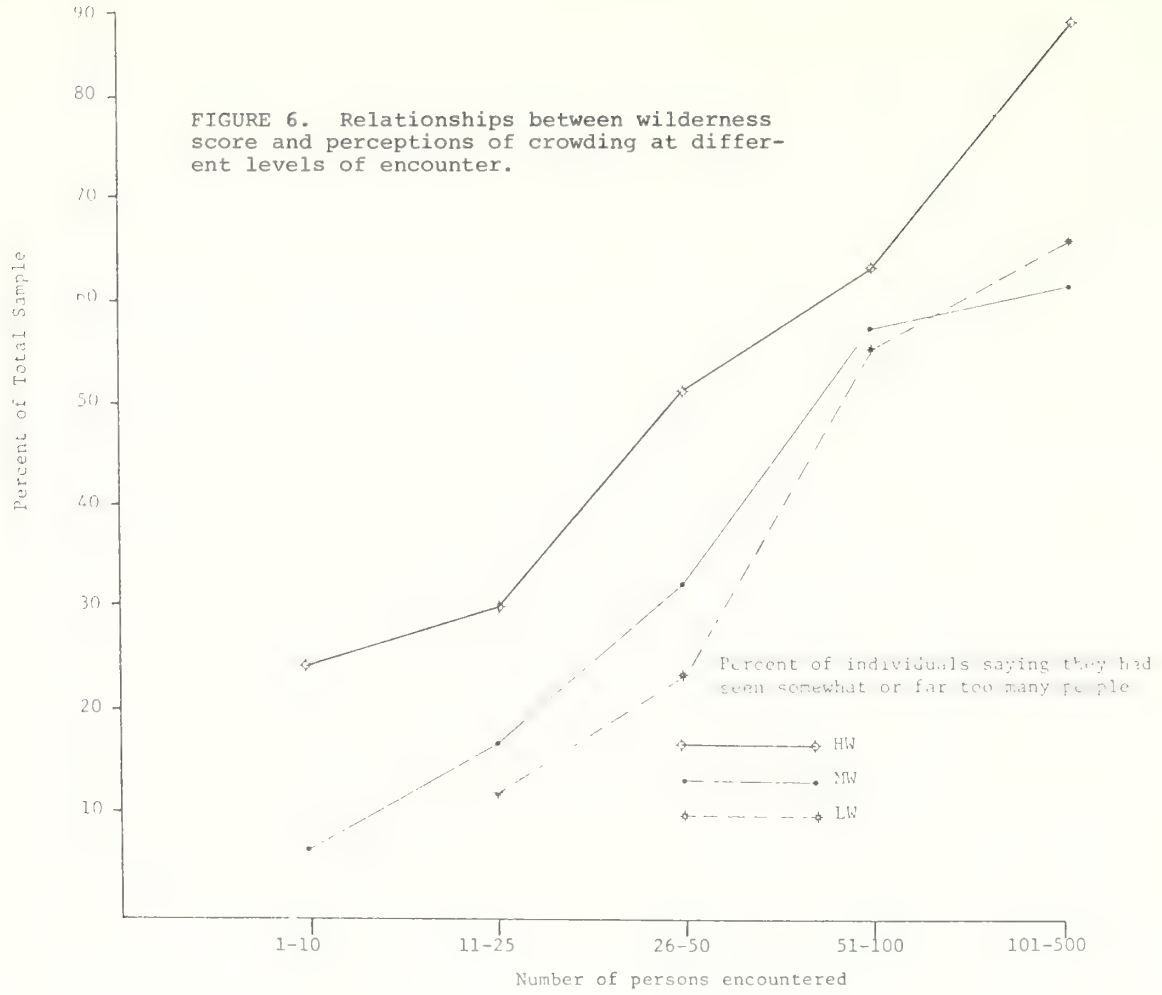

FIGURE 6. Relationships between wilderness score and perceptions of crowding at different levels of encounter.

management objectives, then capacities may be set, but agency personnel cannot continue the assumption that they are managing for "general enjoyment" values.

A further implication is raised in this context. Determinations of crowding perceptions are generally aimed toward current users of a resource. However, it is likely that the nature of users and their expectations of experiences are likely to change over time. Just as the number of users has greatly expanded and agency controls have expanded, it is not unreasonable to assume that the nature of the user will also change. In this sense, examining all potential users may yield a very different series of expectations for the resource from those who presently use it. What we see is a "photograph" of a particular point in time, which may not be representative of either the resource or the nature of the activity.

Consider the present users of the whitewater resource in Dinosaur. Approximately three-fourths are new to the activity. They have no previous experience against which to gauge what they encounter. Consequently, the trip tends to be an overwhelmingly positive one (Roggenbuck 1975). There are few criteria to judge the relative numbers of persons seen, regardless of the number they had encountered (the more they saw, the more they preferred to see; the fewer they saw, the fewer they preferred to see). The other quarter of the users are experienced users. In effect, their use amounts to a tacit agreement with the situation as it now exists. While such a group may complain about conditions, including crowding, they have at least made the commitment to engage in the experience, suggesting they will derive satisfaction. If the experience would have been negative, they could have sought another river to run with fewer restrictions and/or people. Presumably then, those who cannot accept present conditions leave, while those who do not find their satisfactions compromised remain. Thus, evaluation of present users' attitudes may be a positive feedback system. That is, they will reinforce the normalcy of the present situation. However, should use double, will the situation differ? Those who cannot stand such levels of encounter will likely leave, and novices will not know that levels are "too high," for they have no basis in experience. Once again the situation will appear as normal.

This report suggests that perceptions of crowding are experience-specific while users may vary in the intensity of the varying expectations for experience. Examining current users gives a picture of only one situation, and that is likely a static one within a dynamic system. Magnitudes of differences within the user population are not great because much diversity has been selected out. However, this may also suggest that the means for the assessment of crowding have also been selected out. This suggests that perceptions of crowding are not user specific but rather experience specific. Trying to assess crowding through analysis of current users may be no more useful than trying to understand ecology by taking a single picture of a hillside. Rather, we should be concerned with the kinds of experiences we are attempting to provide and then assessing the sensitivity to crowding of these experiences.

LITERATURE CITED

DOLAN, R., A. HOWARD, and A. GALLENSON. 1974. Man's impact on the Colorado River in Grand Canyon. American Scientist. 62(4): 392-401.

DRIVER, B. L. 1976a. Quantification of Outdoor Recreationists' Preferences. Rocky Mtn. Forest and Range Expt. Stn., U.S. Forest Service, Ft. Collins, Colo. Mimeo, 22 pp.

DRIVER, B. L. 1976b. Toward a better understanding of the social benefits of outdoor recreation participation. Southeast Forest Expt. Stn., U.S. Forest Service, Asheville, N.C.

DRIVER, B. L. and S. R. TOCHER. 1970. Toward a behavioral interpretation of recreation, with implications for planning. In B. L. Driver, ed., Elements of Outdoor Recreation Planning. Ann Arbor: The University of Michigan Press. pp. 9-31.

EVERHARDT, GARY. 1974. River running policy statement. National Park Service, Washington, D.C. 2 pp.

HENDEE, JOHN C. 1974. A multiple-satisfaction approach to game management. Wildlife Society Bulletin. 2 (3): 104-1113.

KNOPF, RICHARD C. 1972. Motivational determinants of recreation behavior. Ann Arbor: The University of Michigan. Masters Thesis. 268 pp.

KNOPF, RICHARD C. and B. L. DRIVER. 1973. A problem-solving approach to recreational behavior. Paper presented at the 77th Annual Meeting of the Michigan Academy of Science, Arts, and Letters. Ann Arbor, Mich. The University of Michigan. 21 pp.

KNOPF, RICHARD C., B. L. DRIVER, and J. R. BASSETT. 1973. Motivations for fishing. Transactions of the 38th North American Wildlife and Natural Resources Conference, Washington, D.C. pp. 191-204.

LIME, DAVID W. and GEORGE H. STANKEY. 1971. Carrying capacity: Maintaining outdoor recreation quality. The Forest Recreation Symposium. Syracuse: N. E. Forest Expt. Station. pp. 174-185.

NUNNALLY, J. C. 1967. Psychometric Theory. New York: McGraw Hill.

ROGGENBUCK, JOSEPH W. 1975. Socio-Psychological inputs into carrying capacity assessments for float-trip use of whitewater rivers in Dinosaur National Monument. Unpublished doctoral dissertation. Utah St. Univ. Logan, Utah. 287 pp.

SCHREYER, RICHARD. 1976. Sociological and political factors in carrying capacity decision making. Visitor Capacity Conference, Southwest Region Superintendent's Conf., Natl. Park Service. Ft. Worth, Texas. 28 pp.

SCHREYER, RICHARD, J. W. ROGGENBUCK, S. F. McCOOL, J. MILLER, and L. E. ROYER. 1976. The Dinosaur Natl. Monument Whitewater River Recreation Study. Logan Utah: Instit. for the Study of Outdoor Recreation and Tourism. Utah St. Univ. 170 pp.

STANKEY, GEORGE H. 1971. The perception of wilderness recreation carrying capacity: A geographic study in natural resources management. PhD dissertation, Mich. St. Univ., E. Lansing, Mich. 351 pp.

STANKEY, GEORGE H. 1972. A strategy for the definition and management of wilderness quality. In John V. Krutilla, ed., Natural Environments: Studies in Theoretical and Applied Analysis. Baltimore: The Johns Hopkins Univ. Press. pp. 88-114.

WEST, NEIL E. 1976. An ecologist's thoughts toward determining the recreational carrying capacity of whitewater sections of the Upper Colorado River Drainage. In L. E. Royer, ed., Managing Colorado River Whitewater - The Carrying Capacity Strategy. Logan, Utah: Institute for the Study of Outdoor Recreation and Tourism.

A POPULATION OF LOCAL FISHERMEN AND THEIR PERCEPTIONS OF CHANGE IN A RIVER ENVIRONMENT

Kenneth C. Chilman[1] and Marvin Brown[2]

The continuing increase in user densities at outdoor recreation areas, and the conflicts which frequently arise between different types of users under more crowded conditions are basic problems faced by outdoor recreation managers today (Driver and Bassett 1975).

When one type of use becomes increasingly popular, what are the effects of that increase on the environmental character of the recreation area in terms of other, less popular uses? How are the numbers and attitudes of smaller user groups to be determined for inclusion in the decision processes of managers and planners? Can these minority user groups be conceptualized as "endangered species?" And if so, to what extent should their interests be protected?

A classic example of the above problem situation exists on the lower Current River in south Central Missouri (see Figure 1). Ozark National Scenic Riverways (ONSR), including 100 miles of the Current River, has long been noted for its scenic beauty and for its tempting fishing opportunities (Hall 1958). Because the river flows through steep forested ridges and high rocky bluffs, access is limited. Local Ozark residents have learned to make use of long, flat-bottomed boats called "johnboats" to negotiate the river and its stretches of shallow, rocky rapids. Johnboat travel on the Current River and use of these johnboats for fishing have been a part of Ozark life for several decades.

In recent years, the number of recreationists using the Current River for canoe float trips has increased dramatically. For example, research has indicated that the number of canoe trips below Powdermill Ferry (Figure 1) doubled between the summers of 1972 and 1973 from about 1900 to 3800 (Marnell 1975). What effect has this had on the local Ozark fishermen (generally those residing in the five counties adjacent to the Current River section of Ozark National Scenic Riverways which is administered by the National Park Service)? How many fishermen are involved, how indigenous are they, and how do they perceive changes in their river fishing experiences?

Based on these questions, the following study objectives were formulated: (1) to develop a methodology for estimating the population of local fishermen; (2) to develop a methodology whereby data on local fishermen can be gathered by a field-oriented management planning system; and (3) to determine how fishermen who have used the same river for a number of years perceive changes in the character of use on that river.

RESEARCH APPROACH

In order to meet the objectives listed above a short questionnaire was designed and administered to a representative sample of the population.

ONSR has no formal system of registration for fishermen, nor was there any way to obtain a list of licensed fishermen who reside in the area. Therefore, a mail-out type questionnaire could not be used to gain the information needed. The approach which seemed most logical was to use personal interviews. Since fishermen were known to use a multitude of isolated access points, interview contacts were made by traveling on the river in a motorized patrol boat.

One problem anticipated in this approach was the notoriety of Ozark residents as being generally unreceptive to "outsiders." This problem was compounded by the nature of the activity being studied, that is, fishing from a boat while floating downstream. Contacting fishermen in their boats, while they were float fishing, had to be done cautiously, so as not to create a severe intrusion. To deal with these problems, the required contact time was kept at a minimum and data collection was carried out by uniformed personnel who emphasized their interest in maintaining high quality fishing opportunities. In some cases, contacts were foregone in order to prevent intrusions which might have alienated the target population.

Contacting fishermen on the river for interviews was incorporated into normal management activities. Park Service rangers patrol the river almost daily and are instructed to stop fishermen and check for fishing licenses and conduct other such law enforcement duties. Besides management activities, ONSR's research division conducted a creel census on the lower Current River at least three times a week. It was during the creel census that contacts were made for personal interviews.

A representative sample was obtained by allotting the sampling effort equally among different times of the day, days of the week, and sections of the river.

RESULTS

Population Estimation

The problems of estimating the population of users for a particular recreation area are formidable and sampling difficulties arise when such an estimation is not available (Lucas and Oltman 1971). Many recreation studies have used probability samples allocated by time, location, and the anticipated use pressures for different sites in an area (James and Harper 1965; James and Henley 1968). Others have correlated some easily obtainable factor, such as axle counts, with total recreation use for prediction purposes (Elsner 1970). In those cases the concern was with total use (visitor-days, etc.) without consideration for the size of the population (i.e., a specific group of individuals).

In this project the population under investigation was rather unique when compared to other recreation user studies. Past creel observations have shown that there is a fairly stable group of fishermen from the study area who fish both consistently and frequently (Marnell 1975). These local fishermen could be thought of as a resident population. Making this assumption, one can look to other fields where methods of estimating

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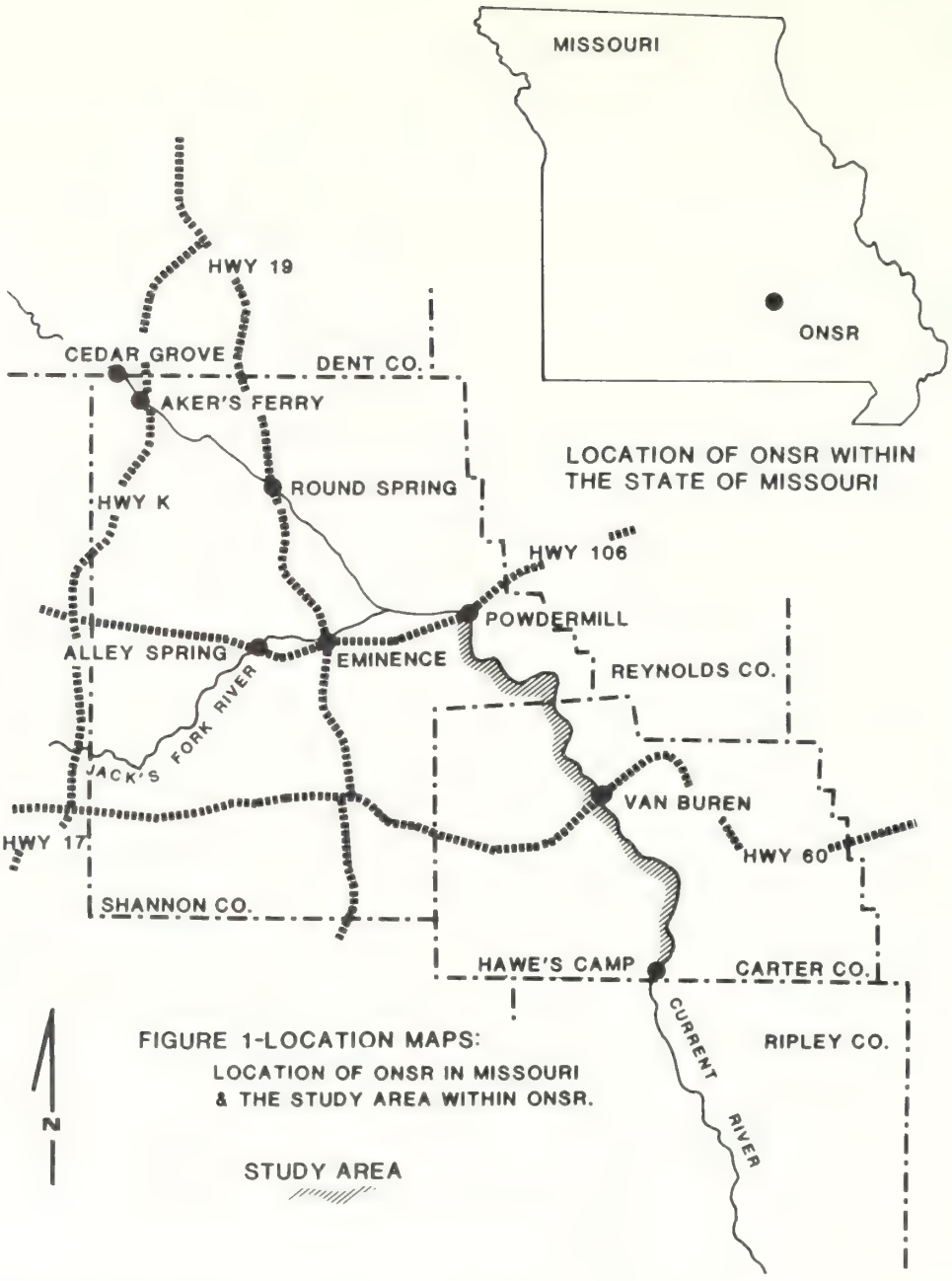

FIGURE 1-LOCATION MAPS:
LOCATION OF ONSR IN MISSOURI
& THE STUDY AREA WITHIN ONSR.

resident populations have already been developed.

An area of study which showed promise in this regard was wildlife management. In this field researchers are often dealing with populations which are indigenous to a defined area. One method developed for estimating these populations is the "Peterson Index Method" (Giles 1969). The equation for this method is as follows: $N = nM/x$

Where N is the estimated total population
M is the number of individuals encountered in the first sample
n is the number of individuals encountered in a second sample
and x is the number of individuals in the second sample who had been encountered in the first sample.

The general idea of the method is that the ratio of "x" over "n" should be the same as that for "M" over "N," or $M/N = x/n$. That is, in a population where a set percentage is marked, and each member has an equal probability of being sampled, the ratio of marked individuals to total individuals in the sample will be the same for each sample and will also be the same as for the total population. Using that idea and basic algebra the equation, $M/N = x/n$, can be converted to read $N = Mn/x$ and thus, be used to estimate the total population.

The "Peterson Index" or capture-recapture method required that two samples be taken in the study and that each member of the resident population have an equal probability of being sampled. Since the nature of fishing (with respect to how many people fish at what time and where) had never been quantified for the Current River, it was felt that a large sampling of times and places must be carried out in order to contact as many segments of the population as was practical. Past creel census information did allow a "student's t" test for significant difference between the mean number of contacts per weekend day and the mean number of contacts per weekday. No significant difference was found at the .95 confidence level and, therefore, each day was sampled equally.

In order to assure an equal sampling effort to different sections of the river at different times of the day, the river and fishing day were categorized as shown in Figures 2 and 3. These two breakdowns were considered most effective since it was estimated that 10-15 miles of river could be sampled in two hours. Accordingly, the six different blocks of the fishing day were cross matched with each of the four sections of the river to create twenty-four total sampling cells. To accommodate the "Peterson Index" one sample was considered complete when all twenty-four cells had been measured. Sampling approximately once every five days allowed for the initial "capture" effort to be completed midway through the summer, leaving the second half of the summer for the "recapture" effort. Since the first sample took approximately 50 days, it was possible to contact the same fisherman twice during that time. When that occurred the second encounter was not included in the capture-recapture tally. "Recapturing" could only occur in the second sample (or second half of the study period) and again, during that period, only one encounter per individual was tallied.

The requirement that each member of the population have an equal chance of being sampled depends on the frequency and duration of his trips. Without any previous quantification of fishing habits, the affect of variations in frequency and duration on the estimation could not be anticipated. Each of the 24 cells shown in Figure 2 occurred 101 times (the number of days in the study period) for a total of 24 x 101, or 2424 occurrences. Each cell was sampled twice so that 48/2424 of the total fishing times and places were attended by the researcher. The probability of the researcher encountering an individual fisherman is that number of times the number of hours a fisherman spends fishing (divided by 2 since each cell is 2 hours long) and divided by the

	1	2	3	4	5	6
TIME	7-9	9-11	11-1	1-3	3-5	5-7
RIVER SECTION A	A1	A2	A3	A4	A5	A6
B	B1	B2	B3	B4	B5	B6
C	C1	C2	C3	C4	C5	C6
D	D1	D2	D3	D4	D5	D6

FIGURE 2: SAMPLING CELL MATRIX

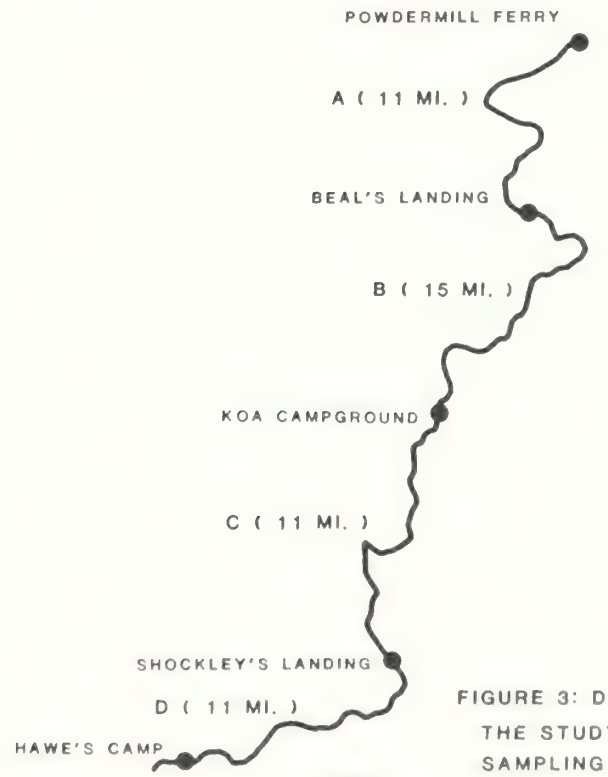

FIGURE 3: DIVISION OF THE STUDY AREA INTO SAMPLING SECTIONS

total cells in the summer, 2424. Examples of different probabilities are shown below.

Occurrence of Researcher On the River	x	Occurrence of Fisherman On the River	=	Probability of Meeting
$\frac{48}{2424}$, or .0198	x	$\frac{4}{2 \times 2424}$, or .0008	=	1.585×10^{-5}
$\frac{48}{2424}$, or .0198	x	$\frac{60}{2 \times 2424}$, or .0124	=	24.442×10^{-5}
$\frac{48}{2424}$, or .0198	x	$\frac{1212}{2 \times 2424}$, or .2500	=	495.000×10^{-5}

As shown above, the probability of being sampled increases, mathematically, at the same rate as the amount of hours spent fishing, the only variable in the entire equation. The affect of varying degrees of probability on the reliability of the "Peterson Index" could have been lessened through a stratification of the fisherman by hours spent fishing per summer. But, without prior knowledge about fishing habits such a stratification would have been arbitrary at best and dependent upon an adequate sample size in each stratum.

In using the "Peterson Index" each cell in the time-place sampling matrix (Figure 2) was sampled once, yielding a total count of 75 local fishermen (repeated contacts excluded). Sampling each cell again in the second half of the summer yielded a total count of 78 local fishermen. Fourteen of those contacted in the second sample were also contacted in the first sample. The results are shown below.

First Sample = 75
Second Sample = 78
Repeats = 14

$$\frac{\text{First Sample}}{\text{Total Population}} = \frac{\text{Repeats}}{\text{Second Sample}}$$

$$\frac{75}{\text{Total Population}} = \frac{14}{78}$$

$$\text{Total Population} = 75/.1794$$

$$= 418$$

As discussed above, the basic premise of "Peterson Index" (that each member of the population has an equal chance of being sampled) could not be fully supported in this study. Stratifying the sample by frequency of trips would have mitigated this problem, but would have resulted in a low, and, thereby, statistically unacceptable number of responses in each stratification.

Fishermen Characteristics and Perceptions

In order to more adequately describe the population, various questions and observations dealt with social characteristics of the fishermen. The data below show that most respondents resided near the river (66%), and most were in the middle age classes (ages 26-65 included 72% of the sample).

Another set of data was analyzed to understand the character of fishing use in the study area. Questions and observations dealt with times when people fished and their past experience.

Information from Tables 3 and 4 points out some of the temporal use patterns. The number of one to six hour fishing trips seem to be almost equal to the number of seven to twelve hour fishing trips. This pattern of use may be explained to some degree by examination of Table 4. In that table the responses indicate that fishing is almost equally distributed between weekend and weekday categories. Weekend trips would be conducive to all day excursions while weekday trips are usually rather short.

Table 5 shows that the number of years respondents have fished in the area is dispersed along a range of one to sixty years. Even though there is a large number of people who have fished less than ten years, the majority of fishermen have done so for more than ten years. This fact is an excellent indication of the indigenous nature of local fishermen.

TABLE 1. Residence and respondents.

Residence	Frequency	Percent of Sample
Local*	126	66
Other Missouri	52	27
Out-of-State	9	5
No Response	5	2
	192	100

*Shannon Co.
Ripley Co.
Reynolds Co.
Dent Co.
Carter Co.

TABLE 2. Age of respondents.

Age Class	Frequency	Percent of Sample
0-15	10	5
16-25	36	18
26-45	82	43
46-65	55	29
65+	9	5
	192	100

TABLE 3. Length of fishing trip.

Length in Hours	Frequency of Responses
1	4
2	2
3	20
4	17
5	23
6	7
7	2
8	18
9	1
10	7
11	0
12	17
No Response (Non-Residents)	74
	192

$\bar{x}$ = 6.2 hours.

TABLE 4. Day of week respondents* usually fished.

Day	Frequency of Responses
Weekends	35
Weekdays	25
Both Equally	22
	82

*Question was analyzed for local fishermen only since nearly all out-of-town fishermen fish on weekends.

TABLE 5. Number of years respondents fished on the Current River.

Number of Years	Frequency of Responses
1-10	58
(1-4)	(39)
(5-10)	(19)
11-20	33
21-30	18
31-40	16
41-50	11
51-60	7
61-70	1
71+	2
	146

Fishing trips per year (Table 6) range primarily between one and sixty times a year. Predominantly though, fishermen take from one to twenty trips a year with less than half of the remaining sample fishing over twenty times in one year.

TABLE 6. Number of fishing trips per year.

Number of Trips	Frequency of Responses
0-10	27
11-20	25
21-30	10
31-40	9
41-50	4
51-60	4
61-70	0
71-80	1
81-90	0
91-100	3
100+	3
	86

Another objective of this study was to determine how local fishermen perceive changes in recreation activity on the lower Current River. Questions were asked to obtain perceptions related to present use characteristics and present versus past use. Other questions pertained to changes in respondents' habits which may have been due to those perceptions. The following tables summarize the results.

It is apparent from Table 7 that respondents perceived more canoeist than fisherman use. Table 8 indicates a perceived increase in canoeists in the last five years. It is also apparent that respondents were not sure whether fishermen have increased or not. Even though 80 of 82 people perceived an increase in canoeists, only 36 of those 80 stated that they have changed their fishing habits (Table 9). But, the ones who have changed their habits did so because of increased river traffic (Table 10). In total, over one-third of the 82 respondents appear to have changed their fishing habits because of a perceived increase in river traffic.

TABLE 7. Type of use observed by respondents.

On this section of river do you see more fishermen, more canoeists, or both equally?	Number of Respondents
More Fishermen	18
More Canoeists	56
Both Equally	12

TABLE 8. Perceptions of increase in river use.

	Yes	No
Do you feel that fishermen have increased in the last five years?	41	41
Do you feel that canoeists have increased in the last five years?	80	2

TABLE 9. Changes in fishing habits.

	Yes	No
Have your fishing habits changed in the last five years? (No longer fish some sections, days, etc.)	36	46

TABLE 10. Reason for change in habits.

	Too Many People, Traffic, etc.	Other
Why have your habits changed?	31	7

CONCLUSIONS

Through an examination of the results, several conclusions can be drawn concerning the study of objectives. Those objectives are again stated as follows: (1) to develop a method of describing the population of local fishermen; (2) to develop a method of data collection which can be incorporated into the normal activities of recreation managers; and (3) to determine the perceptions of local fishermen towards changes in river use.

Description of the Population

The "Peterson Index" did not prove to be an entirely reliable methodology for estimating the size of the local fishermen population on the lower Current River. Stratifying the sample and increasing its size could greatly increase the effectiveness of the Index. With those modifications the Index could become a useful tool for estimating indigenous populations. Such estimates could be applied to any situation where there was a definable group of high frequency users.

Concerning the population characteristics, the predominant age classes are those of people who work. Those who do work will have leisure time available in the evenings and on weekends and will not be seriously affected by heavy traffic during the week. Unfortunately, weekends are also the most desirable times for other users, namely canoeists.

The majority of lower Current River fishermen (66%) are from the local area and have lived there most of their lives. They also have fished for several years (over 10 years for 60%), and have a high frequency of use each year (69% fished over 10 times per year). The basic conclusion to be drawn from this information is that fishing on the Lower Current River is an important recreation activity to local fishermen.

Data Collection Methodology

As the results have shown, adequate data can be collected through river patrol activities by the resource manager. By carefully scheduling when and where sampling should take place the manager could gather data which would offer a good representation of the population and be useful in statistical analysis.

The short, on-site interview proved a good research tool in the study and could be easily administered by resource management personnel.

Perception of Changes in River Use

As discussed in the results, nearly every respondent perceived an increase in canoe traffic over the last five years. One-third of those respondents recognized a change in their fishing habits due to increased river traffic. The high perceptions of increased use would suggest that local fishermen are extremely aware and perhaps sensitive to this increase. This sensitivity may arise out of a conflict between fishing and canoeing, but actual data are not available to substantiate such a conclusion. On the other hand, changing fishing habits because of increased use tends to support the possibility of such a conflict.

In total, local fishermen are highly aware of canoe traffic on the lower Current River. And, observations by the researcher suggest that the majority of fishermen vocalize some resentment towards canoeists. However, this attitude of resentment has affected only about one-third of the population with respect to their actual habits.

LITERATURE CITED

DRIVER, B. L. and BASSETT, JOHN R. "Defining Conflicts Among River Users: A Case Study of Michigan's Au Sauble River." The Naturalist, Spring, 1975, pp. 19-23.

GILES, ROBERT H. Wildlife Management Techniques. Washington, D.C.: The Wildlife Society, 1969.

GISI, DONALD V. "Recreation Expectations of First-Time Visitors to the Ozark National Scenic Riverways." Unpublished M.S. Thesis, University of Missouri-Columbia, 1971.

HABERMEHL, JAMES. "Floater Perceptions of Crowding at the Ozark National Scenic Riverways." Unpublished M.S. Thesis, University of Missouri-Columbia, 1973.

HALL, LEONARD. Stars Upstream. Columbia: University of Missouri Press, 1969.

JAMES, GEORGE A. and HARPER, ROBERT. "Recreational Use of the Ocala National Forest in Florida." Asheville, North Carolina: U.S. Department of Agriculture, Forest Service Research Paper SE-18, 1965.

JAMES, GEORGE A. and HENLEY, ROBERT. "Sampling Procedures for Estimating Mass and Dispersed Types of Recreation Use on Large Areas." Asheville, North Carolina: U.S. Department of Agriculture, Forest Service Research Paper SE-31, 1968.

LUCAS, ROBERT C. and OLTMAN, H. L. "Survey Sampling Wilderness Visitors." Journal of Leisure Research, Volume 3, Number 2, 1971, pp. 29-43.

MARNELL, LEO F. Unpublished In-House Research. National Park Service, Ozark National Scenic Riverways. Van Buren, Missouri.

WEHRUNG, PAT. "Large Group Trips at Ozark National Scenic Riverways." Unpublished M.S. Thesis, Southern Illinois University-Carbondale, 1975.

ASSESSING USER SPATIAL DENSITY PREFERENCE: TOWARD A SOCIAL CARRYING CAPACITY MODEL

Robert H. Becker[1]

Studies of low density forest recreation have been predominantly centered in designated federal wilderness areas. These areas are for the most part isolated from population centers and highly amenable to management of recreation use patterns. Eastern and midwestern state-owned low density use areas are highly accessible to large population centers, are usually managed under various state agencies, and have multiple user entry points making use flow management unusually difficult. Yet, these areas are the principal outlet for the primitive/wilderness recreation desires for the majority of the nation's population. Askham, in describing this trend noted that ". . . for many people, wilderness does not begin or end at the edge of the wilderness boundary. For the majority, wilderness begins at the edge of the concrete" (Askham 1975:3). This edge-of-the-concrete theory of wilderness offers a unique problem for the researcher: that of determining where various users "concrete" ends. Nash points out that most people consider forests an essential characteristic of wilderness (Nash 1963: 7-13). Beyond this point, determining a perceptual base-line for a low density recreation experience is a fundamental component of social carrying capacity.

These queries and previous research results were summarized into the hypothesis that there exists discernible patterns of forest recreation. These patterns were held to be functions of user density over the forest space. Users consciously or unconsciously sought out areas within the spatial forest proximity for their recreational experiences. These user groups within each relative density zone exhibit greater homogeneity on attitudes and preferences toward elements of a recreational system than do user groups over the entire forest area. This exclusivity will be significantly different between the various density zones. This zone homogeneity should be an effective means of classifying users and assessing spatial use estimates.

To test this hypothesis, three objectives were formulated: (1) to determine user perception of the recreational systems of the selected state forests; (2) to evaluate the compatibility of state forest management objectives to user experience perception; and (3) to examine forest users recreation perception in relation to the actual user behavior.

CONCEPT OF SOCIAL CARRYING CAPACITY

Lime and Stankey define carrying capacity as follows: "Recreational carrying capacity is the character of use that can be supported over a specific time by an area developed at a certain level without causing excessive damage to either the physical environment or the experience for the visitor" (Lime and Stankey 1971:174-176). Thus, carrying capacity is a multi-dimensional and dynamic concept involving three major components:

1. Management objectives
2. User perception
3. Capabilities of a natural resource base.

All three components are interrelated, interdependent, and quantifiable. The interrelationship of these components is graphically depicted through a series of sigmoid curves. As carrying capacity is dependent on the interaction between three components, alteration of any one component without subsequent shifts in the other results in an imbalance. The essence and utility of the carrying capacity concept is to understand the dynamics of the recreation system along the acceleration mid-curve. Thus, before resource consumption reaches a point of heavy area impact, the nature of use/user perceptions and behavior must be ascertained to determine compatibility with area management patterns (Figure 1).

This carrying capacity study was based on an empirical study of forest visitors. It was not enough, however, simply to count people as they entered a forest, nor was it enough to count the number using the campgrounds or attending campfire programs. Biologists making wildlife studies know considerably more about the behavior and movements of their subjects than is presently known about forest recreation users.

Questions this study involved were:

1. What was the spatial arrangement of the forest recreation pattern?
2. Were user experience perceptions indicators of user behavior?
3. Did the experiment perception and spatial preferences effect user attitudes toward components of forest recreation systems?

It is important to know how visitors were actually using the forest and how this pattern of use varied as certain conditions changed. For instance, was there a reasonably constant percentage involved in various behavior patterns and using specific areas of the forest? Did the patterns change with alterations in total number of visitors in the forest at any one time? With differences in user socio-economic background? Were the user's actions predicated on the forest resources or the user's bias?

STUDY AREA

The upper Potomac watershed was selected because it is a large forested area within an easy two to four hour drive from Washington, D.C., Baltimore, Maryland, and Pittsburgh, Pennsylvania (Figure 2).

Recreational uses are made of the area including: hunting, fishing, hiking, white-water canoeing and camping. The Forest contains some of the most rugged terrain in Maryland and is the source of both the Casselman and Savage Rivers. Within the boundary of the Forest are the New Germany and Big Run State Parks, as well as two designated primitive campsites, the Bear Pens and White Water.

STATE FOREST USE

Reporting on differential in open space recreation, the Outdoor Recreation Resource Review

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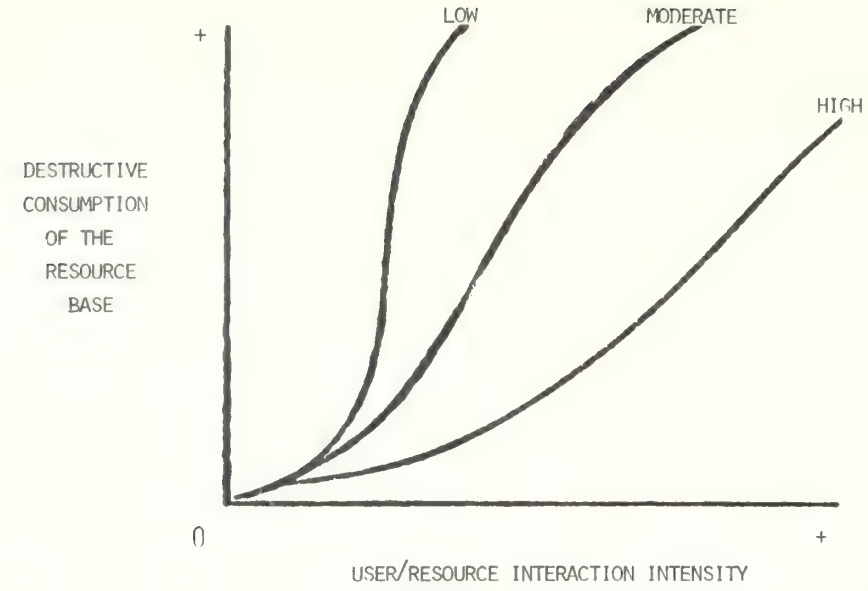

FIGURE 1. Recreation carrying capacity models, alternate area management options.

Commission stated, "the problem is not one of total acres but of effective acres" (as reported in *A Nationwide Outdoor Recreation Plan* 1974:7). From early pilot work on the Savage, it was concluded that different portions of the forest attract different users for a variety of different uses. To respond to the initial objectives of this project, it was determined that a preliminary wide-spectrum recreation survey of the Savage River area was required. One reason for such a general survey was the absence of an indicator of user variance; without such an indicator, the selection of a sample size would have been sheer guesswork. Indicators of: recreation practices; resource and facilities concerns; and user perceptions were needed for construction of the final testing instrument. Perhaps the most important aspect of the pilot was the insight gained into the make-up of the affected population and the spatial-temporal variation of recreational participation over the forest area.

The initial step was to design the pilot sample to gain the information needed for the actual survey. A completely random design was decided upon due to the lack of any prior knowledge of the recreating population on the Savage River area. After preliminary site visits and review of the physical characteristics of the study area, the forest area was divided into study cells (56 acres per cell). Cells were numbered consecutively from the upper left hand corner of a State Forest Platt Map to the lower right hand corner. An arbitrary study group of five percent of the forest was selected. Selection was accomplished through number extraction from a random number table.

Information collected at each cell was grouped according to user encounter frequencies per cell. The spatial arrangement of visitors over the forest area was exhibited via SYMAP. Figure 3 indicated that three distinct zones were present. Data were blocked (post hoc) on density zones and a comparison of means was undertaken.

Table 1, a partitioned table of means and standard deviations, indicated that for the majority of variables, the standard deviation increased as the spatial location where the forest user was observed increased in size. An examination of deviations per variable per zone indicated this between zone relationship. The listing indicated that the direction of the standard deviation for each non-socio-economic variable is consistent. As Zone One accounted for two percent of the total forest area and Zone Two, five percent of the total area, and Zone Three the remainder, Zone Three's gross acreage block was perhaps a reason for the between-group variability.

The results lead to the belief that a spatial density model hypothesis appeared to hold some promise of explanation regarding recreation behavior on the Savage River State Forest.

The number and intensity of difference between users in the three density zones led to the conclusion that density zones attract mutually exclusive groups of users. If this in fact was the case, the traditional methods of user classification would appear to be in question. Variables such as primary activity for visiting the area, occupation and education exhibited no significance.

The above figures, although achieved without the study design based on forest density functions, suggested that follow-up efforts be directed toward further examination of a forest user density model. Through use of density zones, the research is able to improve on study precision by utilizing a sample stratification based on density zones in which users were observed. This cursory effort provided estimates of variance from which future field projects can obtain a sample size needed. Also, areas of concern as indicated by significantly selected variables were highlighted for development of an attitude survey.

TABLE 1. Means and standard deviations

Zones		Length of Stay	Previous Visits	Activity Risk	Activity Type	Camping Accommodation	Camping Location
Factor Z							
2 Moderate	M	3.038	1.154	1.096	3.558	2.192	3.462
	SD	1.546	.364	.358	1.092	1.172	2.062
3 High	M	2.439	1.146	1.049	3.220	2.122	3.293
	SD	.923	.358	.218	1.037	1.122	1.209
1 Low	M	2.971	1.486	1.286	3.143	1.800	3.743
	SD	1.774	.507	.572	1.115	1.208	2.119

		Distance Traveled	Education	Income	Occupation	SMSA
Factor Z						
2 Moderate	M	3.558	2.346	3.769	2.654	2.981
	SD	2.404	1.101	1.148	1.136	2.389
3 High	M	4.000	2.659	4.195	3.024	2.366
	SD	2.324	.911	1.249	1.107	2.034
1. Low	M	4.029	2.743	4.486	2.571	1.971
	SD	2.823	1.094	1.121	1.195	2.121

FOLLOW-UP SURVEY

From the 1974 survey, it was obvious that variance between sites was great enough to divide the forest into relative density stratas for future sampling. Using a stratified sample could enhance study group homogeneity.

Forest use density zones were calculated via Harvard University's Synagraphic Mapping Program (SYMAP). SYMAP sought the spatial location of all data points (each 56 acre cell in the sample was one data point), took the raw frequencies of these points and broke the range into units formatted by the researcher. This study divided the forest into three discrete units representing High Density Use, Moderate Density Use, and Low Density Forest Usage.

From stratification of the Savage River Forest into three homogeneous units based upon levels of use each supports, we expected a gain in precision over a simple forest-wide random sample. The ensuing sample of Savage River recreationists was selected in even proportions from each density level (one-third high, one-third moderate, and one-third low).

The area's distribution of users, as exhibited by the pilot, was quite skewed, with few users per acre in low density areas and high estimates at the Savage River Dam and New Germany Park. The pilot study observations on the Savage River area revealed no users in Poplar Lick area (a primitive area) of Savage River, and 59 persons observed at the New Germany Gate (means for a constructed day of observation). Employing the Demings estimator of s = .21H (H= highest-lowest), we utilized the formula

$$N = \frac{4s^2}{L}$$

where L is the amount of error acceptable to determine sample size (Snedecor and Cochran 1973: 526-529). With a zone frequency standard deviation of 12.39 persons and L at ± one person minimum, N would equal 614 persons. Study sample size for each zone was actually 220 persons.

USER CHARACTERISTICS AND RECREATIONAL PREFERENCES

A survey of the nature of recreation use each area supported was conducted. Factors surveyed through questionnaire interviews of users were: (1) use duration levels; (2) types of use; (3) spatial-temporal variations; (4) user behavior, and (5) perceptions of area resource and facilities. Questions asked elicited information on forest use patterns, socio-economic characteristics of the respondents, their perception of the experience they were having or have had and views toward selected management practices. Statements were constructed regarding these elements of research interest.

A Likert five point scale, ranking responses from strongly agree to strongly disagree, was selected for use in this study because: the Likert scale is unidimensional, each statement is designed to elicit a specific attitudinal response; previous studies have shown it to exhibit ease of field responses; and it has had vast amounts of previous testing and development.

Twelve selected attitudinal statements were arranged randomly on the field schedule. Questions were coded to reflect the area-density zone in which they were distributed. Additional coding was established to determine whether the respondent was a day user or an overnight camper. This required the original three-cell sample sizes to be split. Thus, six cells of 100 respondents per cell were utilized.

TABLE 2. Comparative MANOVAs of the predicted observation density zone. By type of visit factorials on twelve recreational attitudinal statements. Savage River State Forest, Maryland. Summer 1975, sample size 660.

Variable	Source of Variation	Predicted M.S.	Observed M.S.	Predicted F	Observed F
Sightings	Error	1.326	1.354		
	Density Zone	12.825	7.429	9.672*	5.504*
	Type of Visit	.724	.006	.546	.004
	D.T.	2.379	6.738	1.794	4.993*
Harvest	Error	.727	.727		
	Density Zone	9.412	1.364	12.946*	1.825
	Type of Visit	1.345	2.933	1.850	3.925*
	D.T.	.207	.388	.285	.519
ORV	Error	1.518	1.530		
	Density Zone	12.308	7.279	8.108*	4.756*
	Type of Visit	2.743	5.824	1.840	3.806
	D.T.	4.241	4.552	2.744	2.974
Permit	Error	1.022	.999		
	Density Zone	5.275	9.065	5.161*	9.071*
	Type of Visit	.010	.341	.009	.341
	D.T.	.827	3.005	.809	3.007*
Cooking	Error	1.283	1.364		
	Density Zone	58.955	28.011	45.950*	20.529*
	Type of Visit	16.859	27.206	13.140*	19.939*
	D.T.	.621	3.829	.484	2.806
Trails	Error	.911	.962		
	Density Zone	23.789	4.392	26.113*	4.567*
	Type of Visit	2.793	.606	3.066	.630
	D.T.	1.758	.947	1.928	.985
Road Paving	Error	1.102	1.129		
	Density Zone	48.716	1.241	44.207*	1.010
	Type of Visit	13.653	23.674	12.384*	19.265*
	D.T.	.207	.247	.188	.201
Sanitary Facilities	Error	1.173	1.290		
	Density Zone	46.233	4.395	39.414*	3.408*
	Type of Visit	15.515	30.983	13.227*	24.020*
	D.T.	4.448	1.192	3.792*	.924
Clear Cutting	Error	1.254	1.254		
	Density Zone	12.205	14.405	11.489*	9.733*
	Type of Visit	1.551	1.552	1.237	1.237
	D.T.	1.345	1.029	.821	1.073
7-Day Limit	Error	1.361	1.337		
	Density Zone	1.448	10.927	1.064	8.189*
	Type of Visit	21.703	18.333	15.574*	13.709*
	D.T.	3.206	1.679	2.356	1.255
Fee Structure	Error	1.288	1.283		
	Density Zone	4.447	.320	3.453*	.249
	Type of Visit	3.206	4.923	2.489	3.837
	D.T.	.207	5.514	.161	4.297*
Mobile R.V.	Error	1.145	1.192		
	Density Zone	20.479	3.050	17.886*	2.565
	Type of Visit	4.447	8.983	3.884	7.539*
	D.T.	1.345	1.065	1.175	.894
		103.43**	110***		

* Significant at Alpha = .05 or less
** Harmonic Cell Size
*** Observed Cell Size

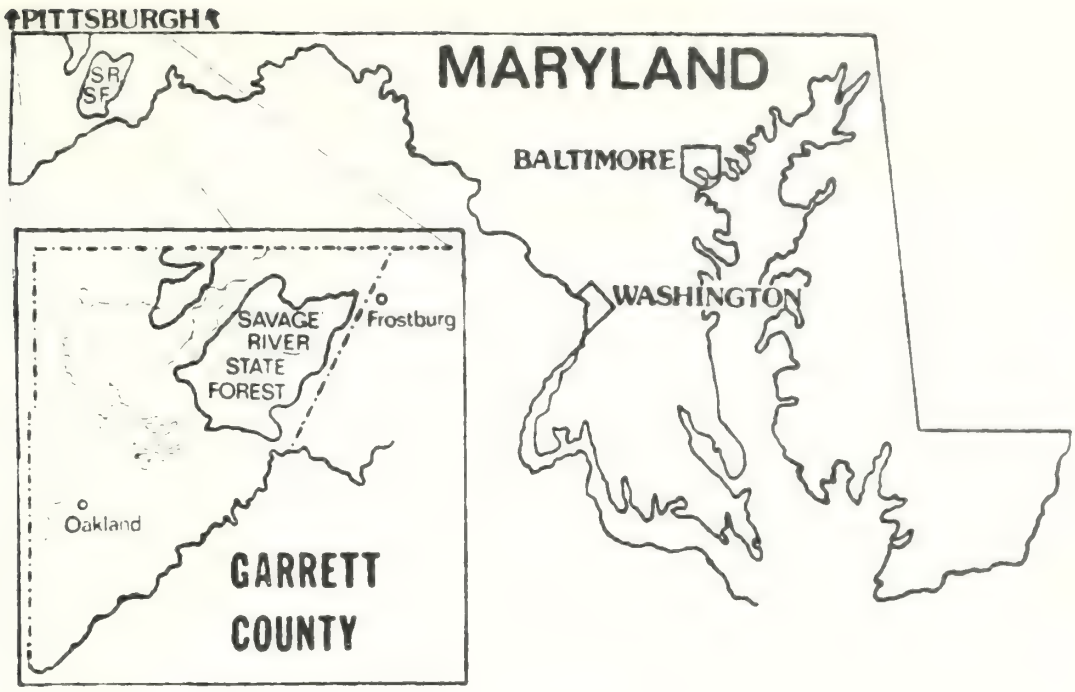

FIGURE 2.

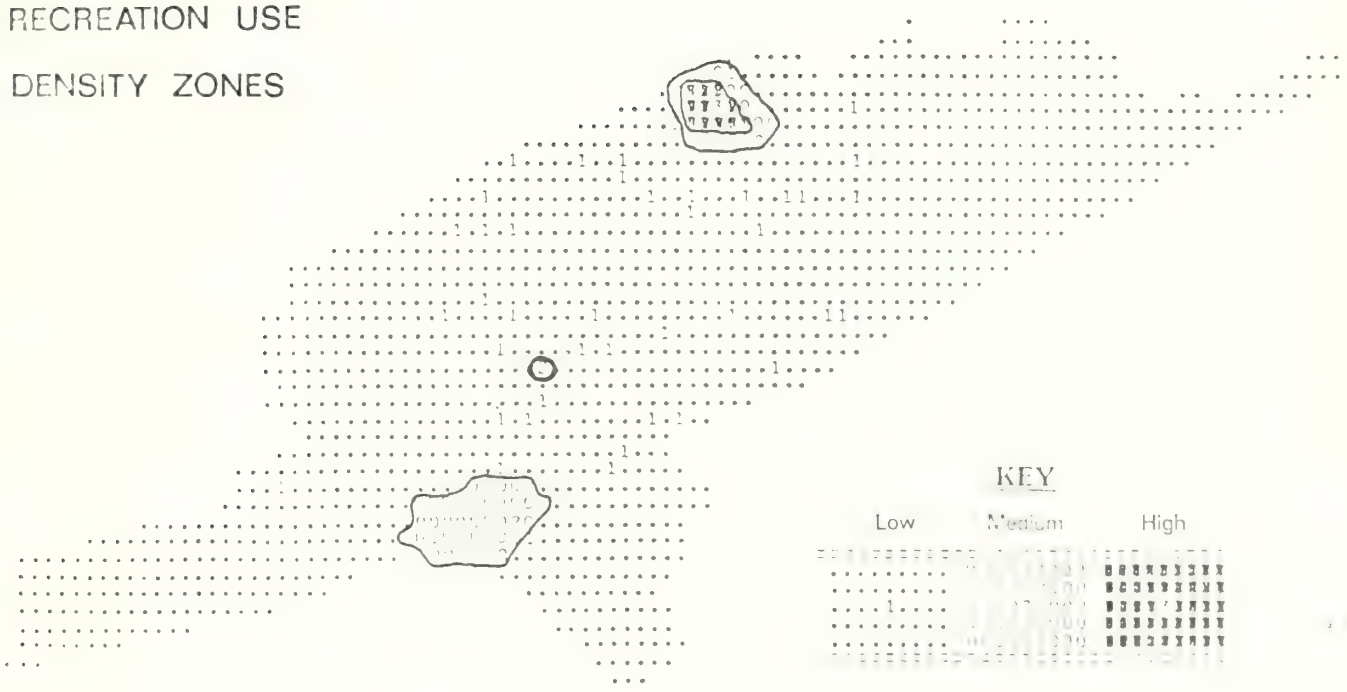

FIGURE 3. Recreation use density zones.

The comparative MANOVA was conducted to check the intensity of the relation between the variables used to predict area density preference and the actual density area where the respondent was observed. Independent predictive variables, extracted from a regression experience-predicting questionnaire, were examined through a predictive Beta regression and a score based on this prediction figure was assigned to each respondent. Experiencial preference variables were adopted from the U.S. Forest Service RIM document (Figure 4). This score was compared to the area in which the respondent was observed. The scores from the predicted zone MANOVA were then compared for their relative efficiency of prediction to the observed density zone MANOVA.

RECREATIONAL EXPERIENCE OPPORTUNITY

Strata Level	
1	A very high degree of basic outdoor skills required. Experiences of adventure, challenge, exploration, solitude, and physical achievement, in the absence of obvious controls, important to the user. Opportunity for extreme isolation. A feeling of being a part of both nature and a wilderness heritage.
2	High degree of basic outdoor skills involved. Feeling of physical achievement at reaching opportunities without mechanized access is important to user. Adventure and challenge is afforded through minimum controls and man-made aids. High degree of opportunity for isolation. A feeling of being nearly primitive and closely associated with nature.
3	A feeling of achievement for reaching the opportunity through challenging motorized access is important. Few controls evident to the user. Opportunities to socialize with others important although less so than at more primitive experience levels.
4	Moderate degrees of outdoor skills are involved. Controls and regimentation afford a sense of security although some taste of adventure is still important to the user. Opportunities to socialize with others about equally as important as isolation. A feeling of being close to nature.
5	Moderate degrees of basic activity skills suffice. Sense of security sought by the user. Regimentation and fairly obvious controls are important. User is aware of opportunity to meet and be with other people--is obviously not isolated. Opportunity to be gregarious with relatively small groups. Some opportunity to use contemporary skills such as snow and water skiing are important.
6	Skills required for basic outdoor activities are minimal. Feeling of security is very important to the user. Learning or beginning skills suffice when supplemented by administrative controls. High degree of opportunity to be gregarious. Abundant opportunity to develop and use contemporary outdoor skills such as water skiing. A feeling of being "next to nature" rather than closely associated with it.

FIGURE 4a. EXPERIENCE-LEVEL OPPORTUNITY CLASSIFICATION

Strata Level	
1	I enjoy exploring areas that are difficult to reach and require physical effort and skill. A feeling of being a part of both nature and a wilderness heritage is important to me. I like to experience the feeling that few persons have been into the area and enjoy the feeling of extreme isolation without supervision or controls.
2	I enjoy the adventure and challenge of going into areas without motorized access. A feeling of accomplishment is achieved through use of outdoor living skills. I like the experience of isolation that is obtained in a managed primitive area. It is important to me to feel closely associated with nature.
3	I enjoy areas that allow me to be close to nature. A feeling of adventure with minimum outdoor living skills in a controlled area is important. While I like the feeling of isolation, I also enjoy meeting other individuals with interests similar to mine.
4	I enjoy areas where few outdoor skills are required. I enjoy natural areas where activities are planned and supervised by park and forest managers. I like the opportunities to meet other people and enjoy activities with others. A feeling of isolation is not important to me.
5	I enjoy visiting areas where I can engage in activities with other individuals and groups. It is important that the area be controlled and free from any natural hazards. I seek outdoor areas that offer a full range of facilities and programs which are for my enjoyment.

FIGURE 4b. EXPERIENCE-LEVEL OPPORTUNITY CLASSIFICATIONS CONVERTED TO FIRST PERSON WITH INCREASED READABILITY

Two three by two factorial multiple analyses of variance (MANOVA) were conducted to determine if there was significant difference between observed users in the low, moderate and high density user, both day and overnight visitors on the selected attitudinal perception questions.

By eliciting response from all non-children group members, a portion of bias exhibited in studies which relied solely on leader opinions was reduced.

1975 FACTORIAL MANOVA: OBSERVED DENSITY ZONE BY TYPE OF VISITOR STAY

Preliminary data runs on the final survey

centered around the two three by two factorial multiple analyses of variances. Twelve attitudinal preference statements as well as selected geographic and socio-economic variables were explored. The twelve statements represented three component elements of the area recreation system. The first component, recreational experiences and behavior, includes the following statements:

1. It is reasonable to expect to see few individuals when visiting a state forest.
2. When visiting the state forest, a good practice is 'take only pictures, leave only footprints.'
3. Use of motorized trail bikes is a proper recreational practice on state forest.
4. When in backwood areas of the state forest, I would not mind filling out a use permit.

In regard to tolerance or preference for sighting individuals, no significant difference was exhibited between day and overnight visitor ($F = .081$, $P \approx .892$). However, differences between density zone users were highly significant ($P \approx .006$). A Duncan's Multiple Range Test indicated that interaction existed between the low density zone day and overnight users. It appears that on the sighting variable the intensity of attitudes centered around zone differences. The low density users, regardless of day or overnight status, preferred seeing less individuals on their visits.

The statement regarding the cliche, "Take only pictures, leave only footprints," exhibited no differences between zones of time of day. Examination of the means indicated that this statement received almost universally strong approval with low mean of 1.9 and high mean of 1.6 (1 represented strongly agree, 5 strongly disagree). This appears rather ironic because interviewed users represent ORV (off-road vehicle) owners, hunters, and other outdoor resource high consumers.

Regarding attitudes toward trail-bike use on state forest lands, significant differences were exhibited between forest user density zones ($\approx .009$) with negative attitudes toward propriety of ORV use increasing as the area density decreased. No significant interaction was exhibited between overnight and day users. Differences in attitudes toward ORV was clearly a function of forest recreation use density. The final statement in Recreational experiences and behavior, the use of permits in back areas, once again exhibited significant differences between density zones (P less than .001) with no significance between day and overnight use and no interaction.

The second component grouping involved four statements related to man-made alterations to the forest area. Facility statements were:

1. Primitive campsites should be equipped with rough tables and cooking facilities.
2. Hiking trails in forest areas should be as primitive as possible.
3. All roads in the state forest should be paved.
4. Sanitation facilities should be provided along primitive trails.

In regard to equipping campsites with cooking facilities, significance was exhibited between both zones (P less than .001) and day or overnight use (P less than .001). However, no significant interaction existed. That indicated parallelism, and a clear distinction between study factors. Comparison of means revealed tolerance for campsite cooking features decreased as density of use decreased. Overnight users, regardless of zone visited were less tolerant and held negative attitudes toward developed sites than did day users.

Responses concerning trail development revealed significant differences between density zones ($P \approx .011$) but not between day or overnight users ($P \approx .0365$). Means of zones centered around a 2.3 ranking or disagreement that all roads should be paved. However, differences between day and overnight users were highly significant (P less than .001). Comparison of means on type of visit revealed that day users tended to hold a more positive attitude (in the neutral range to slight agreement) to paving all roads than did overnight users. Again, perhaps a concession to a limited time of availability to each desired forest area. This was regardless of the actual area the user sought out (no interaction was exhibited).

The final component grouping was related to management practices. Statements were:

1. Clear cutting and thinning in state forests is a proper forest management practice.
2. It is reasonable to limit forest camping to seven days per visit.
3. The more developed the recreational facilities provided, the higher the charge should be to the user.
4. Areas and facilities should be provided for mobile recreation vehicles.

Information regarding user attitudes toward present or potential management practices was solicited as the third and final component of the Savage River State Forest Recreation System. Actual practices in the four statement groupings that were utilized at the time of the survey were clear-cutting for timber management and a fee structure for state park use.

Regarding the clear-cutting practice, significant differences existed between the high use density zone and the two lower density zones. Both low and moderate use zones exhibited a more negative reaction to cutting than did the high density group. All three groups were, however, in the neutral range. This reaction is contrary to what has been contended to be the general reaction toward clear-cutting by outdoor recreationists. This lack of animosity toward cutting was, in the author's opinion, due to the responsible cutting policy of the Maryland Forest Service. Small acreage cuts leaving filter and visual buffer strips meant few visitors realized active cutting was going on or had been practiced.

Significant differences were exhibited between both density zones and day or overnight users (P less than .001 for both factors) on seven days per visit limit. Attitude differences were parallel, with interaction probability at .286. Duncan's Range Test indicated that zone differences existed between the high density use area and the two lower density areas. The higher density users generally agreed with this limitation while the moderate and low density users were neutral on this issue. Day users tended toward neutrality while overnight users held slightly negative attitudes toward such limitations.

A fee structure policy based upon intensity of development of recreation facility drew a fairly vague response pattern. There was no significance between zones ($P \approx .780$) and no significance between day or overnight use. However, there was a significant interaction ($P \approx .014$). The interaction was centered around disagreement with the fee statement by day users of the moderate and high use areas. This was not surprising when examined in conjunction with the current fee

policy by the Maryland Park System which operates the principal areas of the moderate and high use zones. It appeared that users, whether visiting for an hour or the entire day, whether using the swimming impoundment or just a picnic table, were charged the same rate. This was a constant source of complaint on questionnaires in the "Additional Comments" area. The policy has been particularly offensive to local users who are frequent users of areas for short day outings and has resulted in negative attitudes toward any fee structure.

Finally, in regard to state provided facilities for mobile recreation vehicles. No significance was exhibited between density zones ($P \simeq .078$), but was present between day and overnight users ($P \simeq .05$). Mean range comparisons indicated that among high density users, little difference existed among day or overnight users, both were in slight disagreement. In the lower density zones, the pattern was constant, overnight users tended to be neutral while day users held attitudes similar to high use density zone users, in slight disagreement.

Previous research has contended that outdoor preferences and users could be effectively classified by demographic and socio-economic variables. To check the extent of confounding of density zone and type of visit classification with the pre-eminent demographic and socio-economic variables, a second MANOVA was conducted using: education, income, occupation, sex, age, residence, settlement size, and distance traveled as covariates.

In several cases, the regression of the covariates was significant; however, the added explanation was negligible. Significance only existed because of the large degrees of freedom for the regression (7, 647). While the majority of the individual raw regression coefficients for the covariates was under $\pm .1$, the highest was $\simeq .202$. (Education covaried on off-road vehicle acceptance.)

The observed density MANOVA gave insight into the user perception of the recreational system of the Savage River State Forest and the relative compatibility of user perceptions with management practices. To understand the relationship of user recreational perceptions and preferences to actual observed user behavior, a final MANOVA was conducted using the predicted zone preference of user as the new density zone factor (Table 2).

When the two MANOVAs were compared, three themes presented themselves clearly. First, examination of the error terms between the predicted and observed MANOVAs revealed little if any changes. This would indicate that any increase in a sensitivity in the predicted MANOVA over the observed MANOVA was not due to a reduction in random variation, but rather an increase in group homogeneity. The second theme in the MANOVA comparisons substantiated the idea of group homogeneity. The density zone factor of the predicted factorial MANOVA exhibited ten out of the twelve variable F-values higher than the observed MANOVA density zone factor. The purpose of the second predictive MANOVAs was to place individuals into density zone stratas suited to their experience self-perceptions. From the increase predicted density zone mean square the model appears successful at this purpose. Thirdly, the increase in predicted density zone group came with a decrease in the predicted MANOVA's interaction term's mean square and a slight decline in the type of visit factor mean square term. It would appear that, while the increase in the predictor model over the observed model predicts behavior beyond the actual sensitivity level of participation, the overgeneralization is still within acceptable limits for future management practices.

To summarize, conventional recreation measurement techniques have their locus in demand for activities requiring a specific site, and considers demand as demand for a specific type of site or resource. The Savage River Social Carrying Capacity Study suggests identification and measurement of the demand for recreational experiences and their accompanying social values. This effort has demonstrated that demand for recreational experiences can be measured reasonably well for specifically defined groups of actual and potential users, identifying not only preference for areas, experiences and social interactions, but also user predilection for managerial options.

LITERATURE CITED

ASKHAM, LEONARD R. "Wilderness: A Way of Thinking, A State of Mind." Paper presented at the 1975 meeting of the Rural Sociological Society, San Francisco.

BECKER, ROBERT H. "Computer Visualizations as Aids to Forest Recreation Management." Journal of Forestry accepted, publication December, 1976.

FEDERAL WORK GROUP E. "Carrying Capacity of Outdoor Recreation Resources," A proposed report to the National Outdoor Recreation Plan, 1973.

LIME, DAVID W. and GEORGE H. STANKEY. "Carrying Capacity: Maintaining Outdoor Recreation Quality." Recreation Symposium Proceedings, USDA Forest Service Washington, DC: U.S. Government Printing Office, 1971.

NASH, RODERICK W. "The American Wilderness in Historical Perspective." Journal of Forest History, Winter, 1963.

REID, L. M. "Outdoor Recreation Preferences." Unpublished Ph.D. dissertation, The University of Michigan, 1963.

SHELBY, BO and JOYCE M. NIELSEN. "Use Levels and User Satisfaction in the Grand Canyon." Paper presented at the Annual Meeting of the Rural Sociological Society, San Francisco, California, 1975.

SNEDECOR, GEORGE W. and WILLIAM G. COCHRAN. Statistical Methods. Ames, Iowa. The Iowa State University Press, 1973.

U. S. SENATE, COMMITTEE ON INTERIOR AND INSULAR AFFAIRS. A Nationwide Outdoor Recreation Plan. 93rd Congress, 2nd Session, Washington, DC: U.S. Government Printing Office, 1974.

PREVALENCE OF SOCIAL INTERACTION IN A NATIONAL PARK FAMILY CAMPGROUND

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In reviewing the recreation literature about why people go camping, two responses are apparent. Some people say they go camping "to get away from people," while others say they go camping "to meet and visit with people." The focus of this study was to examine the extent to which campers interacted in a modern, developed campground setting. The objective was not only to look at the amount of interaction, but also the intensity or level of social interaction. Social interaction was defined as conversation with people outside one's own camping party: out-group affiliation.

RELATED LITERATURE

ORRRC No. 20, the National Recreation Survey (1962), reported what type of situation people preferred to go camping. Thirty-one percent of all campers preferred to camp "far away from other people," 25 percent preferred "a few campers around," and 25 percent preferred "a place where you can visit and talk with campers." Etzkorn (1964) studied visitors at a public campground in California and found that sociability, more than the natural resource, provided the main attraction for camping. For many people the appeal of camping was not in the opportunity to "escape from others," but rather in the opportunity to meet people in an unrestrictive setting. Etzkorn found that people related their benefits primarily to the "social system of the campground" rather than to the resource.

LaPage (1967) in a study of campgrounds in New England found that approximately 11 percent of the respondents in private campgrounds camped primarily because they enjoyed meeting other campers and that the desire to meet and visit with others was a strong secondary motive for many. Hendee and Campbell (1969) studied the behavior of recreationists at three highly developed campgrounds in Washington State. It was observed that within a few hours of campers arriving at the campground, pleasantries had been exchanged between parties, children began playing with other children, visits were made to other campsites, and "the group of strangers was turned into a community." Conversations with campers revealed that they viewed camping as an opportunity to meet new people. It was concluded that modern, developed campgrounds attract social rather than environment-oriented campers. Burch and Wenger (1967) and Bultena and Lowell (1969) both indicated that campers they surveyed sought either a primitive, simple-style camping or a comfortable, convenience-style camping.

Cheek (1972) examined data obtained through studies supported by the National Park Service. It was found that interaction among strangers in a park setting appears to be the social norm and campers often spent time with strangers they had met in campgrounds. Kauffman (1974) surveyed camping parties in Pennsylvania and found that not all campers seek solitude as a primary reason for their camping experience. Field and Wager (1973) recognized that visitors anticipate a relaxed atmosphere at parks and other outdoor leisure settings. The authors noted that the characteristics of informality and freedom to interact with strangers may be unique to leisure settings and should be encouraged.

PRESENT STUDY

The study was implemented in August 1974 at the Big Meadows Campground in Shenandoah National Park. Data were collected by means of a questionnaire distributed to every individual who signed the campground register. The instructions were to complete the questionnaire just prior to leaving and to return the completed form to either the registration office, to any park ranger, or via mail.[2] The questionnaire had three parts: (1) social interaction matrix, (2) activity profile, and (3) socio-economic descriptive questions. Of the 1,260 questionnaires distributed, 361, or 29 percent, were returned.

A matrix was developed to measure social interaction. On the vertical axis were categories of people interacted with, arranged by proximity to the respondent's campsite. The categories included (1) any member of the immediately neighboring campsite, (2) any other camper in the campground, (3) any other visitors in the national park, (4) any people outside of the national park, and (5) any park ranger or park naturalist. National Park Service personnel could have been encountered anywhere within the park.

Positioned along the horizontal axis were four levels of interaction arranged in a hierarchy. The underlying rationale for the development and arrangement of the categories was based on the probable increasing duration of interaction and decreasing impersonalization.

The first level was "Had Passing Conversation." The use of the word "conversation" was an attempt to eliminate such casual greetings as "hello," "good morning," and "thank you" from being considered social interaction. This level was perceived as being the most impersonal and of least duration.

The second level in the hierarchy was based on the fact that people come from many parts of the country to visit national parks. A very prevalent question among visitors concerns home origins; thus, the second category is "Learned the City or State of Residence." This level was perceived to be less impersonal and necessitated a longer duration of interaction than the previous category.

The third category, "Learned the First or Last Name," was perceived as being even more personal than the previous two categories and was experienced

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[2]A memorandum was sent to park naturalists requesting them to remind the public to return their questionnaire prior to leaving. In addition, a large sign which read "Please Return Questionnaire" was placed on the campground registration door, plainly visible to all traffic.

TABLE 1. Percentage distribution of interaction.

	No Interaction %	Had Passing Conversation With: %	Learned the City or State Of Residence of: %	Learned the First or Last Name of: %	Have Met For a Second Time With: %
Any member of the immediately neighboring campsite	19	81	56	35	29
Any other camper in the campground	21	79	41	24	18
Any other visitors in the National Park	39	61	29	11	9
Any people outside of the National Park	71	29	10	5	3
Any Park Ranger or Park Naturalist	25	75	25	30	19

TABLE 2. Percentage distribution of interaction.

People Met	None %	Low %	Medium %	High %
Any member of the immediately neighboring campsite	19	19	25	37
Any other camper in the campground	21	29	24	25
Any other visitors in the National Park	39	29	19	12
Any people outside of the National Park	71	17	6	5
Any Park Ranger or Park Naturalist	25	39	12	25

during an even longer duration of interaction. The fourth category, "Met for a Second Time," is the perceived peak of the hierarchy, in that the respondent had previously spent time with another and had developed a more personal relationship relative to the other categories.

Table 1 illustrates the categories on their respective axis. The campers were instructed to check all categories of interaction they experienced with each category of people; thus, there were many combinations of answers. These various combinations of answers were collapsed into three categories (see Table 2). Low interaction was simply when only "Had Passing Conversation" was checked. Medium interaction was checking "Had Passing Conversation" as well as another level. High interaction was checking "Had Passing Conversation" as well as two or three additional levels.

RESULTS

Profile of Respondents

The responding camping parties were primarily in the "upper class" on the social status index.[3] Approximately 75 percent were making $10,000 or more per year, while over 80 percent had completed some college education. More than 50 percent were classified professional, technical and kindred workers.

Respondents were generally from young families, with 50 percent having children under ten years

[3]Based on a review of literature which suggested a high correlation among the variables income, education, and occupation, data were collapsed into a social status index (Spaulding 1973).

old and 90 percent having children still living at home. Approximately 40 percent had primary-school-age children in their camping party.

Most of the respondents resided in urban and suburban areas, with an underrepresentation of people from communities of less than 2,500 people. Nearly one out of two camping parties stayed for two or three nights, were returnees to Shenandoah National Park, and/or were tent users.

Social Interaction

Table 1 indicates the percentage distribution of interaction in each of the matrix cells. Approximately 81 percent of the respondents interacted with members of the neighboring campsite, while 79 percent had interacted with other campers in the campground. Three out of four respondents had interacted with National Park Service personnel, while 60 percent had interacted with other visitors to the park. Note the tapering of the percentages from left to right with regard to the four developed levels of interaction, suggesting that the more personal the interaction the fewer and fewer people who experienced it.

The percentages in the upper three levels of the hierarchy indicate one element of desirability, or that one motive of the respondents may have been "to meet with others." If the respondents did not wish to talk with others, or if their motive was "to escape from people," it is likely they would not have spent enough time and effort conversing with others to have learned where they were from, or their names, or have met them for a second time.

There is a relationship between distance from the respondent's campsite and the four levels of interaction. In each case, the percentage of respondents experiencing each level of interaction decreases as you move further away from the respondent's campsite. The most personal interaction, and of longest duration, occurred primarily within the Big Meadows Campground, particularly with members of the respondent's neighboring campsite.

Table 2 indicates the percentage of respondents checking the various combinations of answers, thus providing a better picture of the intensity of interaction than the previous table. For example, 25 percent of the respondents talked with at least one of their neighbors in the campground and also learned either where they were from, their name, or met with them a second time. Based upon the high percentage of "High" and "Medium" interaction, these data imply that the respondents coming to the Big Meadows Campground were not motivated "to get away from others," it is likely they would not have spent enough time and effort conversing to have learned the residence of others, the names of others, or have met others for a second time.

In Table 2, with the exception of the first category of people, there is a tapering of intensity of interaction from left to right. The more intense or personal the interaction, the fewer people who experienced it. Also, as you move further away from the respondent's campsite, there is a decrease in interaction. There is an increase in the "No" and "Low" categories of interaction, while conversely there is a decrease in the "Medium" and "High" categories of interaction as you move away from the respondent's campsite. The most personal interaction (of highest intensity) occurred within the Big Meadows Campground, particularly with members of the neighboring campsites.

DISCUSSION AND IMPLICATIONS

Based upon the data, two conclusions have been drawn:

1) Social interaction among strangers is a prevalent phenomenon at the Big Meadows Campground.

2) Within the package of satisfactions experienced in a national park family campground setting, interacting with strangers may be highly desired and important.

These observations, if correct, have numerous managerial implications for program planning and park design.

If strangers do interact in leisure settings as other researchers have noted and this study supports, what is it about the park environment which provides the impetus for people to interact? Perhaps it is a sense of comradery which campers may experience; perhaps it is the informality of a park setting; perhaps one's social identity and social distinctions are stripped and a person feels anonymous and uninhibited; perhaps it is the lack of time schedules and restrictions; perhaps it is a combination of these reasons and many others. Considering our social conditions today, particularly those in our cities, it may prove valuable for researchers to explore and contrast these environments further.

Prior to discussing management implications of this study, one must ask to what extent is the National Park Service obligated to provide for social experiences? This is a difficult question, but the fact remains that the National Park Service provided for approximately 260 million visits in 1976, and therefore they should be sensitive to the social experience they are providing. Social interaction is only one facet of the social experience in a national park, a facet which may be desirable in developed campgrounds. People may like to meet others and they also may expect to meet others. The National Park Service should be cognizant of the fact that they have and will continue to play a key role in providing opportunity for social interaction, as well as all social experiences, whether it be intentionally or unintentionally.

There are many ways in which park administrators could aid in facilitating social interaction, several of which are implemented at different parks and many of which could be implemented with ease and at little or no expense. There are two distinct areas where more opportunity for social interaction could be provided: (1) park programming, and (2) park planning and design. The following is by no means an exhaustive list.

With regard to programming, either activities could be modified or new activities introduced. For example, at evening campfire talks, the park naturalist could have the seating centralized, allow the people to yell out what state they are from, and be available after the campfire talk for any impromptu discussions. Another example may be on guided nature walks. The park naturalist could try to keep everyone in small groups; have the people work together in small teams at some tasks; allow and encourage visitors to ask questions and and share their knowledge; try to minimize the naturalist's "expert-image" and encourage intra-group discussion and interaction. The intent is to expose things which people may have in common, to help provide an air of friendliness in the park, and provide the opportunity for people to interact.

Many activities can be implemented to encourage social interaction, for example, volleyball, tugs-of-war, horseshoes, wiener roasts with a naturalist present, and possibly dances. Caution would have to be taken in the selection of such activities so as to maintain the integrity of the national park. It is interesting to note that Yosemite National Park has begun a square dancing program.

Planning and design have the potential of bringing people together or separating people. Through careful design, the opportunity for social interaction can be facilitated. For example, at roadside exhibits or at the park visitor center, large action displays or circular displays around which several families could gather as well as ample and comfortable seating would be conducive to social interaction.

The design of the campground, the trail system, and the road system will also influence interaction. Some ways of providing opportunity for interaction may include having small clusters of campsites, group and multiple-party camping units, trails lacing through and around the campground, central play and open space areas, centrally located information and interpretive boards, and community campfire pits. Design research would be very useful with regard to interior designs of facilities and campgrounds. As with programming, there are numerous ways in which planning and design can help facilitate the opportunity for park visitors to interact.

To conclude, this study indicates that social interaction among campers at the Big Meadows Campgrounds was prevalent and, perhaps most consequential, this study suggests that such interaction with strangers may be a desirable attribute of the park experience. It is possible that the National Park Service can encourage and help provide for such a social experience.

LITERATURE CITED

BULTERA, G. L. and L. L. KLESSIG. "Satisfaction in Camping: A Conceptualization and Guide to Social Research." Journal of Leisure Research, Vol. 1, No. 4, 1969, pp. 348-354.

BURCH, W. and W. WENGER. The Social Characteristics of Participants in Three Styles of Family Camping. Research Paper PNW-48. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon: U.S. Forest Service, 1967.

CHEEK, N. H. "Variations in Patterns of Leisure Behavior: An Analysis of Sociological Aggregates," edited by Burch, Cheek, and Taylor. Social Behavior, Natural Resources and the Environment, New York: Harper and Row, 1972, pp. 29-43.

ETZKORN, P. "Leisure and Camping: The Meaning of a Form of Public Recreation," Sociology and Social Research, Vol. 48, October, 1964, pp. 76-89.

FIELD, D. and A. WAGAR. "Visitors Groups and Interpretation in Parks and Other Leisure Settings." Journal of Environmental Education, Vol. 5, No. 1, Fall, 1973, pp. 12-17.

HAAS, G. E. "Recreation and Parks: Social Study at Shenandoah National Park." National Park Service Scientific Monograph No. 10, to be published Spring, 1977.

HENDEE, J. C. and F. L. CAMPBELL. "Social Aspects of Outdoor Recreation--The Developed Campground." Trends in Parks and Recreation, October, 1969, pp. 13-16.

KAUFFMAN, R. A Study of the Effect Which Selected Factors of Proximity and Activity Had on a Sense of Community in Private Campgrounds in the Commonwealth of Pennsylvania, Master's thesis, The Pennsylvania State University, 1974.

LaPAGE, W. Camper Characteristics Differ at Public and Commercial Campgrounds in New England. Research Note NE-59, Northeast Forest Experiment Station, Upper Darby, Pennsylvania: U.S. Forest Service, 1967.

OUTDOOR RECREATION RESOURCES REVIEW COMMISSION. National Recreation Survey. Study Report No. 20, Washington, D.C.: Government Printing Office, 1962.

SPAULDING, I. Factors Related to Beach Use, Marine Technical Report No. 13, University of Rhode Island, 1973.

MULTIDIMENSIONAL BELIEFS OF YOUTH TOWARD NATIONAL PARKS[1]

F. P. Noe[2] and Kirk Elifson[3]

The historical development of park values in the United States has proceeded along preservation and recreation design goals. According to Doell et al. (1973): 59) "the first half of the twentieth century proved that city park systems required land for both native, scenic purposes and for active recreation in all forms. Another quarter century has demonstrated that State and Federal holdings are subject to the same phenomena." The public use of parks has been planned with an understanding that cultural goals are being met by managing for preservation-recreation needs. Involvement by the public in parks has been defined by studies and policy which place them in the role of visitor, sometimes user, and even naturalist. The role of visitor is commonly thought to reflect a temporary status brought about from a need arising out of holiday or vacation free time. The visitor role is usually transitory, intermittent, and performed within a narrow range of behavioral options. At the minimum, mere physical presence in entering a setting is enough to qualify as a visitor. Varied explanations following economic models of demand, demographic models of aggregated social characteristics, and social psychological models of attitudes have depicted the park visitor. Few studies, however, have concentrated solely on what a particular group in society feels about parks. This research therefore concentrated upon society's youth, since attitude formation about parks has not been determined for them.

Youth are a substantially large segment of the American population whose taste is responsible for setting trends in many popular leisure activities. While fashion and play of youth are strongly influenced by commercial interests and often considered banal and frivolous, such influence does not patently eliminate them from having attitudes toward national parks. Research received by the Senate Committee on Interior and Insular Affairs reports that the age group under 25 are "most energetic outdoor recreationists, have the widest span of interest, and enjoy the broadest range of activity" (1974, The Recreation Imperative:52). The data prepared by the Office of Economic Analysis (1973, Outdoor Recreation: A Legacy for America) are reinforced by additional studies which demonstrate youth's interest in "outdoor nature" (Witt 1971:217). Still earlier studies analyzed and reported by Ferriss (1970: 52-54) confirm youth's active involvement in outdoor recreation. The realization that youth represent a sizable number of outdoor enthusiasts as members of their own family or in peer groups is reason enough to know more about how they feel about the parks where much of this activity is performed. As an age group, they are increasing their level of participation over previous years and comprise a majority of the backpackers found in the "backcountry" designated as wilderness areas (Lucas 1971). The age group from 12-17, a span of just six years as compared to individuals age 25-44, hike with a pack, mountain and rock climb to a far greater extent than their elders (1973, Outdoor Recreation: A Legacy for America: 44). A most important reason for understanding what youth feel about national parks grows out of the often blind prejudice that associates them with acts of vandalism, rowdy behavior, boisterous partying, and disrespect for the environment. Incidents of deviant behavior have at times received national coverage in the mass media. Sensational reporting of confrontations between rangers and "greasy-headed Spock spooks" received coverage on the July 4th weekend in 1970. A rash of incidents involving youth in park areas during the early 1970's were not uncommon although accentuated by flower-power, the Viet Nam war, and shifts in educational institutions. More recent difficulties are seen as isolated, individual acts of rebellion rather than organized collective acts of "hippie freaks." That youth groups were party to problems of intergenerational conflict among park users has left behind dissonance among a few managers. It would, however, be a mistake to let such extraordinary incidents of the past cloud judgment toward planning for the future of youth in parks. Although this report will not dwell at length on the issue of interpersonal relations with park personnel and other visiting publics, we do hope to show that youth hold rather firm convictions about national parks, convictions neither inconsistent nor deviant from the social evolution of parks in American society.

Intergenerational conflicts between youth and adults are not premised on some abstract set of conditions between the age cohorts, but on factual life experiences. Youth's experience of outdoor recreation has been described as more active, unlike the aged who pattern their outdoor recreation along more passive lines. The choice of terms active-passive, while theoretically lacking precision, is symbolic of a basic underlying pattern pitting preservation against recreation. Backpacking in wilderness by youth vs. sight-seeing by the aged represents not just physical differences between age groups, but differing impacts upon the natural resources. A park setting is obviously easier to preserve if visitors briefly stop to view a natural wonder, rather than transverse, rest and live on the land. Far too often, the paradox of preservation-recreation has been narrowly conceived as a management problem. The burden of reaching an accord between those values does not rest entirely upon the resource professionals managing park areas. It is far too simple a resolve that "the potential conflict arising between users and those responsible for preserving the natural environment" is totally a bureaucratic issue (Merriam et al. 1972: 59; Hendee et al. 1968; Hendee 1974; Lucas 1966). The conflict is much broader given the history of park development in America and ideologies growing out of the debate between technocratic and anti-technocratic forces over the value of nature vs. technology[4]. But while ideological debate affects the cognitive-affective orientations of decision makers and the public, active participation in outdoor recreation in a specific age group has more direct bearing upon the attitudes of the visiting public. And as already noted, differences in activity preferences between passive-active, aged vs. youth, parallel closely values which reinforce preservation as opposed to recreation beliefs.

Perceptions of natural areas will differ significantly by the opportunities and conditions available to a visitor. Youth are not likely to possess sufficient wealth to acquire many of the more expensive leisure apparatus which influence the kinds of activities sought out-of-doors. (Lucas 1964). Vacation schedules, access to transportation and trained skills in recreating

outdoors are technical, educational and timebound conditions which will affect participation. Given the many variables which affect the response of youth to parks, must we then conclude that there would be no universal orientation about national parks? If we are to accept the statement by Kusler (1974:10) that "parks cannot be all things to all people" and that the will of the people ought to enter into the "propriety of their reasons" for the parks' functioning, then the attitudes of youth should be sought and not just prejudged. To presuppose that there is a single value associated with national parks is a dangerously liable policy which could adversely affect planning and development tactics. To unaccountably claim that "people do wish the national parks to be unspoiled by development and they do wish the heritage to be preserved unimpaired, as the acts and official proclamations have it for posterity" (Darling et al. 1967:209) may be more of an intense wish than a reality. The extent to which such beliefs and values are held as expectations among youth, let alone other age groups in the visiting public, is far from clear. Opportunities and conditions which give rise to such values in society are worthy of investigation because their monitoring will insure a more accurate prediction for future trends.

That "all resources are defined by human perception" (Lucas 1964:409) has enormous implications in the changing dynamics of a society. No value is impervious to change from successive generations who will put to use a resource to fulfill their needs in relationship to current social costs. Because parks are the creation of a social order, their use will be subjected to periodic questioning and redefinition. How the values of preservation-recreation are translated into present social acts by youth will define limits and social boundaries of a park. By way of interpreting an attitude model, words of restraint have been offered by Lucas (1966:121) who cautions that "policy need not be dictated by attitudes and desires of present participants . . . user and potential user perception and attitudes need to be interpreted in a broader context." Such a statement is not uncommon given the lack of previous attitude studies about wilderness and park areas and generally low reported correlations between attitudes and actual behavior within park environments.

METHOD

At this stage of inquiry, a model of how park attitudes are formulated is hypothetical but nevertheless quite useful in choosing variables which may predict shifts in attitude outcome. The model is not final, but subject to modification. The formulation of attitudes among youth during a transitional period of adolescence is fundamental to the socialization process. A number of influences might be more decisive in determining attitude outcomes. A paradigm of the model representing possible determinants of park attitudes is presented in Figure 1.

While the study of attitudes has been central to explaining an individual's relationship to social structure, the correspondence between verbally expressed attitudes and overt behavior has been far from impressive. Among the many causes for the low correspondence between attitude-object-behavior is the failure to recognize that attitudes are situationally grounded. According to Rokeach (1972:195), "this neglect represents a failure to appreciate that an individual always encounters an attitude object in the context of some situation (event, activity, or happening) about which he also has an attitude. Evidence is presented which shows increased predictability by including situational considerations in explaining attitude-behavior outcomes. Because of situational constraints (Bruvold 1973), it was decided that attitudes about parks be specifically directed toward a national park setting. The social settings would be distinguished from urban parks, playgrounds and reservoirs. And since park going is part of a larger subset of leisure and recreation for youth, it was felt that more general attitudes of leisure might very possibly affect park attitudes, so they too were included in the study.

Personal social experiences with parent-peer relations and interpersonal norms governing these interactions perhaps affect youth attitudes toward parks. Problems of parental-peer compliance, schooling and emerging value orientations are accentuated during adolescence and raise serious social issues in the life of the maturing adult. Given the amount of free time available, estimated as high as thirty-six hours a week, it is not surprising to find that the personal social experiences of youth contribute to differing leisure attitudes (Noe et al. 1976). The model used to guide the research is flexible enough so that given the multivariate design applied to the data, variables may be added or deleted to better refine the effects on national park attitudes. Taking an inductive approach which is reductionistic in strategy is necessary given our present narrow state of knowledge. To impute a strictly applied causal interpretation would be unwarranted at this time due to the exploratory intent of this work.

Variables--In constructing a pool of attitude items about national parks, we relied heavily upon wilderness research. Official policy statements from conservation associations and land management agencies about what ought to be a national park, and previous studies that sought to inquire into motives for taking a trip to a national park were referred to as well. A diversity of opinion was evident implying, perhaps, some multidimensional set of beliefs about national parks expanding upon the preservation-recreation dichotomy. While studying the relationship of outdoor recreation and environmental concern, Dunlap et al. (1975:24) found that visiting national parks was strongly related to the belief of "protection of forests and other natural areas for public enjoyment and conversely to preserve areas of unspoiled natural beauty for the future." Reflecting much the same kind of general beliefs, Merriam et al. (1972:266) found both "nature and use oriented beliefs" about state parks including preferences for scenery, preservation, enjoyment, fun, relaxation, solitude and human association. Shifting emphasis to a sample of northeast hikers, Shafer et al. (1969: 194) reported preferences for wilderness ranging from emotional, esthetic, physical to solitary aspects of the environment. Although the individuals sampled are sometimes hikers, campers, park visitors, or part of the general population, recurring beliefs about the natural environment have systematically emerged. Whatever the designations, "traditionalists", "wilderness purists" (Clark et al. 1971; Hendee 1967), "primevalism", "gregariousness" (Harry 1975), the visiting public articulated expectations which are oriented to active recreation, esthetic appreciation, rest, solitude, and human association. These themes provided a framework for developing an item pool which was used to test youth expectation toward national parks. The items comprising the pool[5] were subjected to a principal components orthogonally rotated factor analysis. Five distinct factors which emerged from the analysis are presented in Table 1.

The varimax rotated factors indicated the following mutually distinct beliefs about national

FIGURE 1. A model reflecting possible influences on national park attitudes.

TABLE 1*. Orthogonally rotated factors for selected part attitudes.

VARIABLES	FACTORS					
	1	2	3	4	5	h^2
1. A place to be used as a playground for all ages.	.72					.54
2. A place for outdoor recreation and sports.	.69					.52
3. A place for amusement with a carnival atmosphere.	.53					.29
4. A place to be alone.		.80				.67
5. A place to get some privacy.		.68				.52
6. A place to rest.		.44				.33
7. A place to be with family.			.55			.40
8. A place to travel to.			.47			.25
9. A place for picnics.			.46			.35
10. A place to be with friends.				.54		.48
11. A place for groups to meet.				.51		.38
12. A place to protect forest animals.					.64	.45
13. A place to protect nature's plants, streams, lakes and rock formations.					.63	.43
Percent Common Variance	52.2	19.7	13.1	9.4	5.7	
Eigen Values	3.67	1.38	.92	.66	.40	

*The attitudes were coded (1. Strongly agree; 2. Agree; 3. Undecided but probably agree; 4. Undecided but probably disagree; 5. Disagree; 6. Strongly disagree). Several other attitudinal items loaded below $\pm$ 30 on Factor 1 and 2, but were discarded as were factors 3-5 which had Eigen Values less than 1.00.

parks. The first two factors have Eigen values above one and, given Guttman's criteria, must be considered the strongest of the factors in the data set. Factors three, four and five, while presenting distinct themes relating to family association, peer association and protection of parks are weakly loaded. Therefore, only factors one and two are interpreted and they are defined as follows:

1. Playfulness (Factor One). The items loading on this dimension represent a tendency to view national parks in a setting in which it is legitimate to expect that outdoor recreation activities will be allowed. Given the otherwise active sporting and extracurricular activities engaged in by youth, this attitude appears to complement their overall leisure preferences. Although the value of play is strongly held, it is tempered by youth's unwillingness to define a park as a carnival atmosphere. Apparently, revelry and festiveness associated with commercial entertainment are not acceptable, at least in a national park setting. The cognitive separation which accepts

play but not commercial entertainment is clearly distinguished by youth. That commercial entertainment facilities are not the kinds of development which youth associate with national parks is shown. By the same token, there is a tendency among youth to sanction commonly thought of outdoor recreation activities. The precise limits to which they would tolerate development of the park environment for that purpose is not clear. Having first identified this factor, tolerance limits can be identified as part of subsequent inquiries.

2. Solitariness (Factor Two). The traditional belief of seeking a personal individual relationship with nature is also affirmed by youth. The feeling of being alone, in private, while in contact with nature provides a counterpoint to the gregariousness of modern society. The romantic value often portrayed in American folklore of the rugged individualist leaving it all behind is very much a part of our wilderness heritage. The belief of youth that the national parks provide such a setting is consistent with beliefs of the sophisticated wilderness user. If this belief is based on a profound need to experience nature unfettered, or a result of interpersonal spacing norms, neither reason has been satisfactorily explained. Stankey (1972) has reported that approximately 80 percent of wilderness users desire solitude which involves seeing only those visitors in their own party. Cicchetti et al. (1973) also report that the willingness to pay for outdoor recreation is significantly reduced when user contacts increase. Although the precise social limits for experiencing solitude in wilderness are not known, nor necessarily the reasons for that motive, we are fairly confident that this attitude is basic to a park experience for youth. The precise limits of solitude in terms of relationship with the environment, the visiting public, the numbers within a visiting party will be problematic to future studies.

The independent variables having possible effects on attitudes toward national parks were selected to include areas of behavior responsive to attitude formation. Prior studies on parent-peer compliance indicated that these were pivotal social interactions. The choice of variables was therefore directed toward measuring the influence of either the parent or peer on use orientation to national parks. The variables chosen have proved useful in past analysis in measuring parent-peer influences in predicting a use motivation encouraging upward mobility, increasing educational experiences, maintaining heterosexuality or guiding career and vocational goals[6]. In addition to parent-peer relations, the actual frequency with which parks other than neighborhood playgrounds are used might be a decisive factor in shaping beliefs about national parks. When visiting a national park, contact with Park Service personnel might also be a determinant of park attitudes. Both sets of questions were included to test this possibility[7]. Since participation in parks represents only part of the time devoted to leisure activities, it was hypothesized that a youth's more general leisure orientations would likewise have some effect. Two scales developed in an earlier study (Noe et al. 1976) were evaluated to test whether they would produce any effect on park attitudes[8]. All independent variables were subjected to a multiple regression analysis to evaluate the relative contribution in explaining the dependent variables.

In examining the effects of the independent variables, the adolescent sample was differentiated on the basis of age and sex. In the work of Gordon (1971:932) a distinct difference was postulated for early adolescence, the years 12-15, and late adolescent years, 16-20. We distinguished between the sexes because of continuing interests that the variable raises in regard to educational attainment and academic success.

Sample--Data for this study were collected during the summer and fall of 1974 from public school students in grades 9-12 in a suburban county in the greater Metropolitan Atlanta (Georgia) area. A random sample was drawn from a universe of 24,289 students compiled from official school records. A total of 600 adolescents (301 males and 299 females) attending 21 schools were interviewed, representing 78.0 completion rate. Parent and/or student refusals totaled 28 and the remainder were lost cases who could not be located due to incorrect addresses, absence from the city or an inability to be contacted by phone. Appointments were made prior to the one-hour interview which took place in the respondent's home and all interviewers were white and matched by sex with the respondents. The respondents were evenly distributed by grade, sex, school and represented the universe from which they were drawn. It is important to note that the sample was intentionally drawn from the white population, thus the choice of county. DeKalb County is relatively white (86.3 percent), affluent (1970 median white family income was $12,824) and educated (1970 median educational attainment was 12.5 years). This population represents a cross section of Americans who visit national parks. The youth surveyed are white, male and female, ages 12-18, suburban, coming from families where over 50 percent of the fathers had some college education and only 2 percent had no high school education. The sample does not include lower socio-economic groups, the working class, nor the welfare poor. The sample does reflect the attitudes of adolescents towards the use of their leisure and the effect that parents and peers have upon their orientations toward national parks.

FINDINGS

The park attitude items were factor analyzed by a principal components orthogonal rotation technique and then factor scored for each respondent. Playfulness and solitariness emerged as two distinct factors which relate to national parks. Taken together they represent beliefs among youth in the necessity of using parks for outdoor recreation and a haven for being alone. It is very unlikely that every avenue potentially associated with beliefs about national parks was investigated. Although youth are known to be socially involved with peers, we did not find the expected intercorrelation among them identifying national parks as a setting to be with friends, family or in peer groups. The fact that sociability occurs may be derived more from normal associations in the community than an inherent goal in visiting a park. Christensen (1973:12) found "that an individual's use of recreational facilities is related to his personal communities or the influence of his family, friends, workmates and relatives." The joint and collective use of a park may be more a necessary means for achieving a visit rather than a consequence of a visit.

The protection/preservation items were not substantially intercorrelated and yielded weak factor loadings. Given the recent publicity and interest in environmental degradation, we thoroughly expected a stronger, more consistent response from the youth. Appreciation for environmental concerns had been reported to be associated with visiting parks (Dunlap 1974:24). But the contradicting fact is the finding that high school students are less than knowledgeable about environmental issues (Ditton et al. 1974). The association between preserving the environment and a national park being one site in which to accomplish that goal has not been readily communicated to youth. Whatever the reasons, just two

factors emerge which loaded sufficiently to be interpreted among the set of beliefs put before the youth sample.

From the results of Factor 1, Playfulness, no variable explained more than a fraction of a percent in predicting variance. Playfulness is interpreted as defining a youth's response to outdoor recreation. An active participation in sports and related extracurricular activities limits the scope of Factor 1. Neither of the age groups or sexes were particularly differentiated on any set of variables, nor were there any indications of a consistent pattern that might be investigated in the future. Since the effects of schooling, extracurricular activities and involvement in sports for both sexes were not investigated, they may offer an avenue of useful inquiry in the future. But for the present at least, the effects of more general attitudes toward leisure, relationships with peer and parent, and specific experiences related to a national park were not indicators in predicting an attitude of playfulness toward national parks. In the end, we can only surmise that factors related to schooling, patterns of leisure activity, and factors affecting travel may be more significant in shaping an attitude that reflects the use of a national park as an area for participating in outdoor recreation. Such inquiry must await further analysis and modification of the model used in this study.

In evaluating the results for the female age 16 to 20 on Factor 2 (Solitariness), three variables, egalitarian rebelliousness, contacts with park personnel, and independence from peers, accounted for 20 percent of the explained variance. The leisure attitude of youth involved with egalitarian rebelliousness represents a value which places a high premium upon engaging in leisure activities individually and outside of an organized social group. Barriers establishing inequalities of participation based upon predetermined standards are not acceptable according to this attitude. The predictability is understandable with respect to solitariness since being alone in a wilderness area is reinforced by a leisure attitude which seeks to promote individualistic purposes. As contacts with park personnel became less negative and more friendly, pleasant, and informative, the attitude of solitariness toward national parks increased. The interpersonal relationships with park personnel offer a friendly and reassuring response in which a female will feel secure in pursuing an individualistic and personal relationship with nature in an otherwise unstructured environment. The final variable of independence from peers, while approaching statistical significance, points out again the individualistic response of youth who look upon a park as providing a solitary experience wherein few peer relationships facilitate solitariness. The favorability of contacts with park personnel and

TABLE 2. Regression analysis of the dependent variables for females 16 to 20 years.

Dependent Variable: Factor 2 (Solitariness)					
Independent Variable	Zero-Order Correlation	Unstandardized Regression Coefficient (b)	Standard Error of b	Beta Weight	F-Ratio
Equalitarian Rebelliousness	.36	.02	.01	.36	15.58 (P.001)
Contacts Park Personnel	-.17	-.05	.03	-.21	5.26 (P.01)
Independence From Peers	-.11	-.03	.02	-.16	2.60 (N.S.)
			R^2 = 20%		

TABLE 3. Regression analysis of the dependent variables for males 16 to 20 years.

Dependent Variable: Factor 2 (Solitariness)					
Independent Variable	Zero-Order Correlation	Unstandardized Regression Coefficient (b)	Standard Error of b	Beta Weight	F-Ratio
Park Visits	-.31	-.13	.04	-.31	7.79 (P.001)
Equalitarian Rebelliousness	.20	.21	.07	.26	7.64 (P.001)
Closeness to Mother	-.17	-.09	.05	-.16	3.44 (P.01)
Contacts Park Personnel	-.28	-.05	.03	-.16	2.90 (P.05)
			R^2 = 22%		

individualistic beliefs about leisure and the personal security of being apart from a peer reference group give youth the necessary social reinforcement and lack of peer pressure to develop a highly solitary, individualistic attitude which views the park as a place for a personal relationship with nature.

In contrast to the 16 to 20 female age group, the older male adolescents (16-20) were somewhat different when predicting solitariness although they shared the favorability of contact with park personnel and believed in leisure reinforcing egalitarian ideas. Yet, it was the lack of park visits that predicted more of an attitude reflecting solitariness. Since visiting a park is a highly individualistic and prized occurrence, it is perhaps thought of as something special, not ordinary, and infrequently experienced. The implication is quite clear that it is not necessary to have frequent visits to a national park in order to be able to appreciate a solitary relationship. While the lack of dependence upon peers for the female signaled an important social relationship, increasing self-reliance for the male was fostered by a lack of closeness to mother. The lack of affection in a relationship between mother and son is more likely to create a machismo self-image for the male adolescent. The combined effect of these variables explained approximately 19 percent of the variance for the 16-to-20-year old male on Factor 2 (Solitariness). For the male and female of early adolescence (12 to 15), little variance was explained on Factor 2 (Solitariness). None of the independent variables, singularly or combined, served to explain the factor.

CONCLUSION

Results of this inquiry have produced a few insights that are worthy of consideration. The findings do not explain a tremendous amount of variance, since that is an unrealistic goal given the multidimensionality of behavior and the scant theoretical knowledge available. The results have demonstrated for the late adolescent of both sexes that solitariness in national parks is reinforced by more general leisure beliefs, relations with park personnel and interpersonal relationships. These factors influence a young person during this critical period in the socialization process into accepting a pattern of expectations toward parks. Ignorance of a youth's beliefs, of the social situation, and dominant interpersonal relations will dilute the effectiveness of any effort in developing a model of behavior. Although the concept of an attitude replaced the idea of an instinctual explanation, arguing direct correspondence between an attitude and behavior is simply to fall prone to the same deterministic assumptions that plagued the instinctivists. Any future effort to understand man's relationship to his natural environment and its institutionalization in part as parks must recognize the complexity of the phenomena.

The complexity associated with the development of any model must of necessity allow continual modification as new, more powerful predictors are found. Just because "behavior is complex and has multiple causes" (Heberlein 1973:28) is no reason to abandon the search. It is equally axiomatic and more obvious perhaps to assert that change is also a reality and further that to observe one to one correspondence is unlikely in explaining behavior. But again, complexity and change are not sufficient to give up the search. Numerous skills, knowledge, and opportunities together combine and enter into the selection process and they, too, must be sought in determining whether visitors indeed possess an attitude toward national parks. Knowledge of an attitude toward parks and factors contributing to it are being sought to increase understanding, not to effect attitude change. Accepting the basic premise of democratic action, resources managers and policy makers are not motivated to "induce widespread and general attitude change among visitors or potential visitors" (Heberlein 1973:30). Rather, their efforts are far more modest in trying to understand what individuals believe, how they are affected and why they do certain things in order to better understand visitor behavior. Understanding alone can serve to guide a policy maker who may well realize that he cannot change a visitor's behavior. Knowing that there are limitations has frequently reduced frustration and dissonance among managers. Saving oneself from blind prejudice by knowing that not all young people are park trouble makers has an effect upon outlining a more rational policy. Since changing forces and movements in society are ever present, studies into the behavior of man and his environment can be used only in the broadest sense.

Determining the nature of youth's attitudes toward national parks propelled our investigation. Playfulness and solitariness emerged as distinct sets of attitudes reflecting in part the expectations of youth. The strongest relationships in explaining the factors occurred for solitariness. Those predictors open up an avenue of inquiry which will be directed toward learning more about influences on solitariness. The absence of predictable relationships toward playfulness calls for a reappraisal of the model and other areas of living associated with the youth's schooling, extracurricular activities, travel and SES which may have a more pronounced effect on his attitude toward national parks. Future inquiries will carry on this multidimensional approach.

FOOTNOTES

[1]Support for this research was granted by the National Park Service, U.S. Department of the Interior, in order to complete the analysis of the data.

[2]National Park Service Science Center, National Space Technology Laboratories, Bay St. Louis, Mississippi 39520.

[3]Department of Sociology, Georgia State University, University Plaza, Atlanta 30303.

[4]In a recent essay by Samuel Florman, "In Praise of Technology" Harper's (November) 1975, the debate between the technologists and anti-technologists continues. The issue of nature rejuvenating man was raised and the ways it can be experienced is still being debated. An excerpt will illustrate the problem.

> And pity poor Roszak (anti-technologist) for the dreadful indignity he has had to endure:
>
> > A personal anecdote: a sign of the times. Several year ago, on a cross-country trip, my family and I were foolish enough to visit Yellowstone National Park during the summer crush . . . There was not an inch of solitude or even minimal privacy to be found anywhere during the two days we stayed before giving up and leaving. Never once were we out of earshot of chattering throngs and transistor radios or beyond the odor of automobile exhaust . . .
>
> Reply by Florman (technologist):
>
> How nice it would be for a select few of us if Delphi and Yellowstone could be set aside for

our personal enjoyment, with the masses restricted to places such as Coney Island, more suited to their coarser sensibilities. But, unfortunately our fellow citizens will not grant us such special privileges. Certain places that cannot possibly handle crowds or that would be seriously damaged by crowds, are restricted to select scholars or other people of special qualifications. But, in general, those of us who would be tourists have little choice but to learn to put up with others who have similar desires and equal rights. Fortunately, although Delphi may be crowded, there are a hundred other ruined Greek temples that are not, and if Roszak would only leave his car in the Yellowstone parking lot and hike a mile or two into the woods, he can still find all the wilderness he could desire.

[5]I am going to read some uses of parks at the *National Level* that are not necessarily near your home, for example Mammoth Cave, Everglades, Fort Sumter, Great Smoky Mountains or Yellowstone. I want you to tell me how you feel about each activity. (Likert Format). 1. A place to protect forest animals. 2. A place to be with friends. 3. A place for groups to meet. 4. A place to be with family. 5. A place to play games. 6. A place to joke and kid around. 7. A place to be used as a playground for all ages. 8. A place to rest. 9. A place to travel to. 10. A place to get some privacy. 11. A place to sleep at night when traveling. 12. A place to protect nature's plants, streams, lakes and rock formations. 13. A place for amusement with a carnival atmosphere. 14. A place for picnics. 15. A place to be alone. 16. A place to preserve historical deeds. 17. A place for outdoor recreation and sports.

[6]Among variables differentiating parent-peer influences were the following:

(1) *Alternatives to Outcomes Controlled by Parents.*
This is a series of items which describes a young person's perceptions of his abilities to find other sources of money should his parents give him less and to find places to go when he wants to escape from his parent's house. The four items comprising the index were Likert-type scales. An item that was especially discriminating read, "I know that if my parents gave me less money I could get enough money from other sources to make up for it." The complete set of items is found in Smith (1970:860-873).

(2) *Alternatives to Paternal and Maternal Reference Resource.*
The scale delineates a set of items which shows a general orientation of the young person to turn for guidance to the strongest individual which is an alternative to both the father and the mother. An example of such items included in the four-item scale read, "When I have a decision to make, the ideas of my brothers or sisters are almost worthy of careful consideration." (Smith 1970:860-873).

(3) *Independence from Peers.*
The four Likert-type items comprising this scale express the idea that a young person is not upset being a loner or an oddball and doing things outside of the peer-group context. An example of such an item reads, "I wouldn't mind being thought of as an oddball." The scales are found in the research of Schwartz (1971:446).

(4) *Independence from Family Authority.*
A series of four Likert items measures the degree to which the young person is willing to disagree with the wishes of their parents. A typical item reads, "Children should obey all the rules their parents make for them." The full set of items is available in Schwartz (1971:447).

(5) *Closeness to Father.*
A series of four scales measures the affection and affiliation that a young person has with his father. The items were scored following a Likert routine, and one item was, "When you were growing up, how did you feel about how much affection you got from your father?" The scales were taken from the *Youth in Transition* study by Bachman (1970).

(6) *Closeness to Mother.*
A series of three Likert-type items expresses the degree of affection which a young person experiences with his mother. An example of the scale reads, "When you were growing up, how did you feel about how much affection you got from your mother?" The full set of items can be found in the *Youth in Transition* study by Bachman (1970).

[7]When you think of recreation, sometimes the place where you engage in such activities may be taken for granted. We would like to ask you some specific questions about one such place--namely, parks.

(1) In Georgia and neighboring states in the South, there are several state and national parks. How many times in the last two years have you visited one of these? 1. Never. 2. 1 time. 3. 2-3 times. 4. 4-7 times. 5. 8-15 times. 6. 16-40 times. 7. 41 times or more. 8. Don't know.

(2) When you have had contact with National Park Service personnel, how would you describe your experience? 1. Very pleasant. 2. Pleasant. 3. Neither pleasant nor unpleasant. 4. Unpleasant. 5. Very unpleasant. 6. Not applicable (no contact).
Could you tell me a little more about what you mean by your last comment? Response generally fell into the following categories: 1. Pleasant (contact). 2. Informative. 3. Friendly. 4. Polite. 5. Helpful. 6. Enforcer. 7. Prosecutor. 8. Not enough contact.

[8]*Achievement Sociability.*
The items comprising the achievement sociability scale indicated interest on the part of the adolescent in using free time activities as a way of acquiring status in the community and demonstrating to their friends and the community their personal qualities. The full list of items is indicated in Table 1. The general themes center on the values of success, getting ahead, getting along with other people, showing off one's good points, which are all positive items directed toward increasing the status image of the individual during his discretionary time. (Likert Format). 1. Free time activities which are part of a person's upbringing give direction and purpose to life. 2. Getting ahead in life is certainly helped by engaging in proper free time activities. 3. Knowing how to get along with the kind of people who can help you succeed in life can be learned through free time activities. 5. Free time activities help to raise a person's

image in the eyes of the community. 6. People's free time activities give them a sense of being part of a continuing heritage. 7. A person can really show his friends what he is really like through his leisure activities. 8. Recreation has a way of bringing out a person's good points. 9. Success is achieved not only through work, but also through one's fun and relaxation. 10. Belonging to the right kinds of clubs and organizations is important for a young person's reputation. 11. Free time activities should be used primarily to develop a person's abilities to make it in the world. 12. A sense of accomplishment should come out of free time activities. 13. Doing certain kinds of free time activities is useful for keeping good relations with your parents. 14. Free time activities are one way of getting to know the practical things in life. 15. An adolescent is easily identified by what he or she does in his/her free time. 16. Half the battle of having fun in your free time is being with the right kind of people. 17. There is nothing wrong with people glamorizing their free time activities.

Egalitarian Rebelliousness.

The second factor which will also be utilized as a dependent variable indicates that the young person views certain negative values which possibly occur during leisure participation. These items are negative and express disdain for individuals who attempt to be exclusive, limit their participation with others, tend to hide behind the cloak of arguing for happiness as if all free time activities provided fun, or wish to provide for future generations. The items tend to demonstrate the openness with which the adolescent approaches free time and disclaims personal participation that is based upon limited interaction. The items comprising the scale generally denote a negative response to using one's free time in a socially circumspect, exclusive manner. 1. Free time activities do not contribute to a person's happiness. 2. A person should not spend his free time among members of his own class of people. 3. People should not be with their own kind when having fun. 4. It is not important to preserve our free time activities for future generations. 5. People are better off openly displaying their free time activities to everybody.

REFERENCES

ADAMS, ROBERT, ROBERT LEWIS, and BRUCE DRAKE. 1973. Outdoor Recreation, Appendix "A." Washington: Bureau of Outdoor Recreation.

BACHMAN, GERALD C. 1970. "Youth in Transition." Volume II, Ann Arbor, ISR.

BRUVOLD, WILLIAM. 1973. "Belief and Behavior as Determinants of Environmental Attitudes." Environment and Behavior 5(June):202-218.

CHRISTENSEN, JAMES and DEAN YOESTING. 1973. "Social and Attitudinal Variants in High and Low Use of Outdoor Recreation Facilities." Journal of Leisure Research 5(Spring):6-15.

CICCHETTI, CHARLES and V. K. SMITH. 1973. "Congestion, Quality Deterioriation, and Optimal Use: Wilderness Recreation in the Spanish Peaks Primitive Area." Social Science Research 2(March):15-30.

CLARK, ROGER, JOHN HENDEE and FREDERICK CAMPBELL. 1971. "Values, Behavior and Conflict in Modern Camping Culture." Journal of Leisure Research 3(Summer):143-159.

DARLING, F. FRASER and NOEL EICHHORN. 1967. "Man and Nature in the National Parks," pp 206-235 IN Walt Anderson (ed.), Politics and Environment (Pacific Palisades: Goodyear Co.).

DITTON, ROBERT and P. JOHNSON. 1974. A Survey of Recreation Behavior and Attitude Patterns of High School Juniors and Seniors: Implications for Environmental Education and Resource Management. University of Wisconsin: Sea Grant Report No. 5.

DOELL, CHARLES and LOUIS TWARDZIK. 1973. Elements of Park and Recreation Administration. Minneapolis: Burgess Co.

DUNLAP, R. E. and R. B. HEFFERNAN. 1974. "Outdoor Recreation and Environmental Concern: An Empirical Examination." Rural Sociology 40(Spring):18-30.

FERRISS, ABBOTT. 1970. "The Social and Personality Correlates of Outdoor Recreation." Annals of Political Social Science (May)46-55.

GORDON, CHAD. 1971. "Social Characteristics of Early Adolescence." Daedalus 100(Fall):931-960.

HARRY, JOSEPH. 1975. "Social Class, Wilderness Attitudes, and Behavior." ASA Meeting, San Francisco (August).

HEBERLEIN, THOMAS. 1973. "Social Psychological Assumptions of User Attitude Surveys: The Case of the Wilderness Scale." Journal of Leisure Research 5(Summer):18-33.

HENDEE, JOHN C. 1967. Recreation Clientele--The Attributes of Recreationists Preferring Different Management Agencies, Car Campgrounds or Wilderness in the Pacific Northwest. Dissertation: University of Washington.

HENDEE, JOHN C., WILLIAM CATTON, LARRY MARLOW, and FRANK BROCKMAN. 1968. Wilderness Users in the Pacific Northwest--Their Characteristics, Values and Management Preferences. Portland: USDA Forest Service Research Paper PNW-61.

HENDEE, JOHN C. 1974. "A Scientist's Views on Some Current Wilderness Management Issues." Western Wildlands (Spring):27-32.

KUSLER, JON. 1974. Public/Private Parks and Management of Private Lands for Park Protection. Madison, Wisconsin, Institute for Environmental Studies, Report 16.

LUCAS, ROBERT. 1964. "Wilderness Perception and Use: The Example of the Boundary Water Canoe Area." Journal Natural Resources 3(3):394-411.

LUCAS, ROBERT. 1966. "The Contribution of Environmental Research to Wilderness Policy Decisions." Journal of Social Issues 22(October): 116-126.

LUCAS, ROBERT. 1971. "Hikers and Other Trail Users" pp 113-122 IN E. Larson (ed.) Recreation (Forest Service Upper Darby, Pa.: USDA.

MERRIAM, L. C., K. D. WALD and C. E. RAMSEY. 1972. "Public and Professional Definitions of the State Park: A Minnesota Case." Journal of Leisure Research 4(Fall)259-274.

NOE, F. P. and KIRK ELIFSON. 1976. "The Pleasures of Youth: Parent and Peer Compliance Toward Discretionary Time." Journal of Youth and Adolescence 5(Spring):37-58.

ROKEACH, MILTON and PETER KLIEJUNAS. 1972. "Behavior as a Function of Attitude Toward Object and Attitude Toward Situation." Journal of Personality and Social Psychology 22(No. 2):194-201.

SCHWARTZ, AUDREY. 1971. "A Comparative Study of Values and Achievement: Mexican-American and Anglo Youth." Sociology of Education, 44(Fall): 483-462.

SHAFER, ELWOOD and JAMES MIETZ. 1969. "Aesthetic and Emotional Experiences Rate High with Northeast Wilderness Hikers." Environment and Behavior 1(December):189-196.

SMITH, THOMAS ERVIN. 1970. "Foundations of Parental Influence Upon Adolescents: An Application of Social Power Theory." American Sociological Review, 35(October):860-873.

STANKEY, GEORGE. 1972. "A Strategy for the Definition and Management of Wilderness Quality" pp 88-114 IN John Krutilla (ed.), Natural Environments: Studies in Theoretical and Applied Analysis. Baltimore: John Hopkins Press.

U.S. COMMITTEE ON INTERIOR AND INSULAR AFFAIRS. 1974. The Recreation Imperative. Washington: U.S. Government Printing Office.

WITT, PETER. 1971. "Factor Structure of Leisure Behavior for High School Age Youth in Three Communities." Journal of Leisure Research 4(Fall):213-219.

PAY AS YOU PLAY: AN ANALYSIS OF ATTITUDES TOWARD A FEE-FOR-USE APPROACH TO OUTDOOR RECREATION

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INTRODUCTION

As interest and participation in outdoor recreational activities in the United States continue their dramatic rise, additional strains are placed on already crowded facilities. The abilities of federal, state, and local governments to expand existing supplies of outdoor recreational facilities are hampered by tight budgets and priority systems which place recreational development at a distinct disadvantage. The major focus of this paper is on fee-for-use as a means for expanding outdoor recreational opportunities. Of particular interest here are:

1) The attitudes of respondents toward fee-for-use recreation to augment governmental expenditures for recreational development.

2) A tentative assessment for several popular outdoor recreational activities of the amount(s) respondents would be willing to pay for access to such activities and facilities.

JUSTIFICATIONS FOR THE STUDY

The demand for outdoor recreational opportunities has skyrocketed in the United States. The Bureau of Outdoor Recreation estimated that for the period 1960-2000 demand will increase by 400%, or about twice as fast as the projected growth in population (Jensen 1973). This will mean, of course, that the costs of supplying such resources --their acquisition, development, and maintenance --must skyrocket as well to meet the increases in demand. Since recreation must compete with other budget priorities in times wherein increases in federal, state and local budgets in many cases are not keeping pace with inflationary trends, the prospects for supplies keeping pace with these demands are not bright. A recent analysis of the situation for the state of Louisiana, for example, seems to indicate even greater projected imbalances for that state than for the country as a whole (Grimes and Pinhey 1976). In light of facts such as these, increased attention is being paid to the roles of other revenue sources, particularly fee-for-use and private profit-making enterprises, to supplement other governmental efforts (Outdoor Recreation Resources Review Commission 1962; National Policy for County Parks and Recreation 1964). This shift in attention has not taken place, however, without some misgivings:

> Many . . . have rather reluctantly agreed to increased reliance on entrance fees and other charges as a means of raising revenue. Some of them seem to have been afraid of adverse public reaction--an attitude which experience to date has not supported. Others had convictions that outdoor recreation should be "free." Only when they realized that appropriations from general tax revenues would probably be inadequate to deal with the recreation problem they faced, were they willing to accept the idea of user charges. These charges seem to be a lesser evil than mounting demands from the public and inadequate funds. (Clawson and Knetch 1966: 279-280)

WHO SHOULD PAY: A DEBATE

The issue of who should pay for recreation has been a perennial one. Essentially, if these arguments are reified they may be summarized by two "ideal types"[3]--on the one hand are those who argue that the "public" should pay and on the other hand are those who insist that "users" should bear the costs. A salient argument for "public" support is the "social externality" thesis which states that:

> . . . outdoor recreation is essential to a full and well-balanced personal life; that those who participate in outdoor recreation tend to become more productive citizens; and thus the welfare of the whole nation is enhanced. According to this argument, everyone benefits in some way, and even those who do not partake of outdoor recreation have an interest in its ready availability, and should be willing to help pay for it. (Clawson and Knetsch 1966:267)

The second position, on the other hand, insists that the "user" himself is the primary beneficiary of outdoor recreational activities and it is, therefore, his role to provide the revenues for the acquisition, development and maintenance of these facilities through some sort of fee-for-use system.

Throughout the history of our country recreational policies suggest that the "public benefit" ideology has held sway for most periods. However, despite its dominance, other factors including tight budgets and extreme supply-demand imbalances brought about by the rapidly increasing demands noted above have exerted pressure for increased "user" participation in the financing of outdoor recreation in America. (National Policy for County Parks and Recreation 1964).

This paper will focus on the fee-for-use alternative and will examine the attitudes of a sample

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[3]See Gerth and Mills (1958) for a description of the "ideal type" as proposed by Max Weber.

TABLE 1. Either now or in the future, How would you recommend that funds be obtained for the improvement of recreational facilities in Louisiana?

	Diversion of Money From Budget	Increase In Taxes	Fee-for-Use	Combination	No Answer	Total
A. The Entire Sample	33.3	3.7	32.2	20.6	10.1	926
B. Income Level						
Under $6,000	37.8	5.4	25.0	15.2	16.6	319
$6,000-$9,999	30.1	2.9	41.9	18.1	7.1	172
$10,000-$15,999	30.2	3.1	36.8	24.7	5.1	198
Over $16,000	30.6	3.0	29.8	33.7	2.8	172
C. Occupational Level						
Professional, Technical and Kindred	24.5	0.8	39.6	34.3	0.8	133
Business Managers, Officials and Proprietors	24.1	0.7	40.6	30.7	3.9	106
Clerical and Sales	19.7	1.2	45.8	33.2	0.0	51
Craftsmen, Foremen and Kindred	27.2	2.1	48.8	15.1	6.9	102
Operatives and Kindred	48.7	7.3	19.2	9.0	15.8	74
Unskilled, Service and Domestic	40.7	4.1	22.5	17.3	15.5	151
D. Educational Level						
College Degree	21.3	1.4	34.5	40.7	2.1	162
1-3 Years College	23.1	1.8	35.0	35.4	4.8	162
10-12 Years	38.2	3.1	38.6	13.6	6.5	343
Less than 10 Years	38.2	6.9	23.2	9.2	22.5	285
E. Location of Residence						
Rural	46.3	4.8	22.9	9.6	16.4	213
Incorporated	36.4	1.3	30.0	20.7	11.5	167
SMSA	27.2	4.0	36.5	24.9	7.3	546
F. Recreational Activity Level						
Actives	32.5	3.2	33.7	23.3	7.3	574
Inactives	35.4	5.0	28.6	13.5	17.5	352

of Louisiana citizens toward both the general principle and its application to a variety of specific outdoor recreational activities.

MEASURES AND SAMPLE

This section of the paper describes the measurement of the variables and the nature of the sample. Our first measure dealt with the relative priority of fee-for-use as a means for providing additional funding for outdoor recreational facilities. Here we asked our respondents the following question: "Either now or in the future how would you recommend that funds be obtained for the improvement of recreational facilities in Louisiana?" The response alternatives for the questions were: "Diversion of money from the budget," "increase in taxes," "fee-for-use," or some combination of the above.

Our measure for the fees question was as follows: "Check the amount you would be willing to pay for one day's use of the activities listed above (assuming that the facilities could be made available only through a fee-for-use system)." The amounts were $1, $2, $5, $10, and $25.

We chose a set of popular outdoor recreational activities for use here. Following Hendee (1969) who divided recreational activities into two groups: "appreciative," those activities in which participants typically enjoyed the environment without modifying it; and "consumptive," those activities which involved "taking something from the environment." We selected two activities typical of the former group, camping and beach activities, and two activities typical of the latter, fishing and hunting.

Controls for a variety of other characteristics of our respondents thought to influence responses to issues such as those in our paper were also applied. These included income levels, occupation, educational attainment, place of residence, and whether the respondent had participated in

TABLE 2. Amounts respondents were willing to pay for access to beach facilities (percentages).

	$1.00	$2.00	$5.00	$10.00	$25.00	Total
A. TOTAL	26.5	30.8	23.4	11.8	7.6	620
B. INCOME						
$0-3999	33.0	34.0	15.5	14.6	2.9	103
4000-7999	29.7	30.6	17.9	2.9	8.7	113
8000-11999	29.2	27.7	30.7	7.3	5.1	137
12000-15999	26.8	24.4	30.5	11.0	7.3	82
16000+	28.8	32.4	25.2	8.6	5.0	139
C. OCCUPATION						
Unskilled	33.8	24.6	15.4	16.9	9.2	65
Oper	37.8	24.3	18.9	13.5	5.4	37
Crafts	19.4	31.9	26.4	11.1	11.1	72
Clerks	27.9	30.2	23.3	11.6	7.0	43
Man	30.8	26.9	30.8	9.0	2.6	78
Prof	28.0	29.7	33.1	4.2	5.1	118
D. EDUCATION						
Under 3 Yrs.	65.4	23.1	3.8	7.7	0.0	26
4-6 Yrs.	23.1	33.3	23.1	15.4	5.1	39
7-9 Yrs.	28.8	25.8	18.2	19.7	7.6	66
10-11 Yrs.	22.6	21.0	32.3	12.9	11.3	62
H.S. Grad.	24.7	28.5	27.2	12.0	7.6	158
1-3Yrs College	31.4	33.9	25.6	5.0	4.1	121
College Grad.	32.5	32.5	21.7	9.4	4.8	83
Professional	28.6	32.7	28.6	6.1	4.1	49
E. AREA OF RESIDENCE						
Rural	31.6	30.5	25.3	6.3	6.3	95
Incorporated	28.7	28.7	29.8	8.5	4.3	94
Urban	28.9	29.4	23.1	12.0	6.5	415
F. PARTICIPATION						
Participant	22.1	35.2	23.5	13.0	6.0	312
Non-Participant	30.6	26.3	23.2	10.5	9.3	308

the particular activity during the previous year.[4]

Sample. The sample of respondents used in this study was a six-stage cluster sample of 926 respondents residing in the state of Louisiana. Procedures such as those used are thought to produce a fairly representative sample.[5]

FINDINGS

The presentation of our findings will be divided according to the goals of our paper in two sections:

1) The assessment of fee-for-use as an alternative to other forms of funding for outdoor recreational development.

2) An analysis of the amount our respondents are willing to pay for a typical day's use of selected outdoor recreational activities.

Fee-for-Use. In an effort to assess the opinions of our respondents toward fee-for-use, we aksed the following question: "Either now or in the future how would you recommend funds be obtained for the imporvement of recreational facilities in Louisiana?
Table 1 contains these data. Diversion of monies from other budget areas received the most support for funds to improve recreational facilities in the state, but fee-for-use was mentioned by only 1% fewer respondents than the "diversion" alternative. Almost one-third of the sample suggested fee-for-use as a means for providing additional revenues and resources. In light of our argument above concerning general budget structure and the fact that other budget priorities will rank higher than recreation in the minds of legislators,[6] these responses take on additional significance. When we divided the members of our sample according to *income levels*, no clear pattern of association emerges. Higher income groups tended to prefer the "combination of approaches" alternative more often than did lower income groups. Too, fee-for-use was slightly more popular among the higher income groups, but differences were small.

When controlling for *occupation* (Table 1-C) the fee-for-use alternative seemed especially attractive to the top two-thirds of the occupational

[4] To date there is little information concerning the prediction of willingness to pay. We therefore made the assumption that variables which have been shown to be associated with other recreational phenomena such as participation (Dunlap and Heffernan 1975) and with phenomena such as environmental concern (Buttel and Flinn 1974; Harry et al. 1969) would also predict willingness to pay.

[5] See Lindsey et al. (1975) for a more detailed description of our sampling techniques.

[6] See Grimes and Pinhey (1976) for a discussion of legislators and their attitudes toward recreation budgets.

TABLE 3. Amounts respondents were willing to pay for one day's access to camping facilities (percentages).

		$1.00	$2.00	$5.00	$10.00	$25.00	Total
A.	TOTAL	16.0	25.4	29.6	20.3	8.7	705
B.	INCOME						
	0-3999	29.3	26.0	25.2	13.0	6.5	123
	4000-7999	16.5	31.6	24.1	17.3	10.5	133
	8000-11999	15.3	29.9	37.6	10.2	7.0	157
	12000-15999	15.7	31.5	28.1	18.0	6.7	89
	16000+	11.8	24.3	36.8	21.7	5.3	152
C.	OCCUPATION						
	Unskilled	17.1	24.3	30.0	18.6	10.0	70
	Operatives	20.0	30.0	32.5	10.0	7.5	40
	Crafts	18.4	23.0	29.9	14.9	13.8	87
	Clerical	12.2	32.7	26.5	20.4	8.2	49
	Man	11.4	23.9	42.0	19.3	3.4	88
	Prof	11.9	30.2	37.3	14.3	6.3	126
D.	EDUCATION						
	Under 3 Yrs	36.1	36.1	13.9	8.3	5.6	36
	4-6 Yrs.	23.9	26.1	26.1	15.2	8.7	46
	7-9 Yrs.	18.5	34.6	22.2	18.5	6.2	81
	10-11 Yrs.	20.3	18.8	33.3	18.8	8.7	69
	H.S. Grad.	13.9	26.6	31.8	16.8	11.0	173
	1-3 Yrs. College	13.5	31.6	33.8	17.3	3.8	133
	College Grad.	19.6	27.8	32.0	14.4	6.2	97
	Professional	7.5	22.6	50.9	11.3	7.5	53
E.	AREA OF RESIDENCE						
	Incorporated	21.0	25.7	35.2	12.4	5.7	105
	Rural	28.8	25.2	25.2	15.3	5.4	111
	Urban	13.6	29.2	32.0	16.9	8.3	472
F.	PARTICIPATION						
	Participant	12.7	25.3	27.5	24.3	9.9	310
	Non-Participant	18.4	25.2	31.3	17.2	7.7	395

groups, while the bottom third preferred the "diversion" alternative. Almost half of the craftsmen group opted for fee-for-use, while only 20% of the unskilled group favored this alternative.

The next control applied was *educational attainment* (Table 1-D). Here preference for the fee-for-use alternative was directly related to educational level--those with higher levels of education preferred it to alternatives a bit more often than otherwise, and lower educational groups preferred the "diversion" alternative more often.

When we looked at the *residence location* of the sample (Table 1-E), rural residents were the most favorably disposed toward the "diversion" alternative and least favorably disposed toward the "fee-for-use" approach. The group most favorable to the fee-for-use was the group of respondents living in SMSA's.

When we compared *recreationally active* individuals to those who were inactive during the past year, the "actives" were more likely to choose fee-for-use and the inactives were more likely to chose "diversion." However, more than two-thirds of both groups chose one of these two alternatives (see Table 1-F).

Beach Activities. Our first specific recreational activity was beach-related recreation, an "appreciative" activity. The modal amount which our respondents were willing to pay for one day's use of beach facilities was $2.00 (see Table 2-A). When we divided our sample into various *income levels* it was clear that responses to this question were at least minimally related to these levels, with lower income respondents being slightly more likely to indicate lower amounts than higher income respondents (for example, as seen in Table 2-B, about 67% of the lowest income group preferred the $1.00 or $2.00 category, while only 61% of the highest income group checked these amounts).

Turning now to the *occupational* groupings, lower status groups generally selected lower fees-for-use, while higher status groups selected higher fees. Professionals opted for the $5.00 fee while unskilled workers chose the $1.00 fee for beach access.

Our third control variable was *educational level* (Table 2-D). Generally the lower the educational attainment of the respondent, the more likely he was to choose the two lowest fees for one day's use of beach facilities (those with less than 3 years of schooling overwhelmingly chose the $1.00 lowest amount, while the modal response for those respondents with higher educational levels tended to be either $2.00 or $5.00). For all educational categories the $10.00 and $25.00 categories contained few respondents.

We next divided our respondents by *area of residence* (see Table 2-E). Here the only salient difference was that the rural group tended to indicate lower fees than the two more urban categories. For example, while 62% of the rural

TABLE 4. Amounts respondents were willing to pay for one day's access to hunting facilities (percentages)

		$1.00	$2.00	$5.00	$10.00	$25.00	Total
A.	TOTAL	25.8	25.5	28.3	13.9	6.5	569
B.	INCOME						
	0-3999	34.3	24.8	22.9	12.4	5.7	105
	4000-7999	25.0	30.8	25.0	15.4	3.8	104
	8000-11999	20.0	30.8	33.3	10.0	5.8	120
	12000-15999	18.6	22.9	30.0	17.1	11.4	70
	16000 +	24.8	26.4	28.0	14.4	6.4	125
C.	OCCUPATION						
	Unskilled	28.3	26.7	18.3	16.7	10.0	60
	Operatives	27.3	27.3	33.3	6.1	6.1	33
	Crafts	14.5	26.1	29.0	21.7	8.7	69
	Clerical	18.8	37.5	34.4	0.0	9.4	32
	Man	16.9	33.8	26.0	16.9	6.5	77
	Prof	24.8	25.7	36.6	10.9	2.0	101
D.	EDUCATION						
	Under 3 Yrs	56.7	20.0	16.7	6.7	0.0	30
	4-6 Yrs	38.5	17.9	20.5	20.5	2.6	39
	7-9 Yrs	16.7	28.8	25.8	13.6	15.2	66
	10-11 Yrs	23.2	23.2	32.1	17.9	3.6	56
	H.S. Grad	21.4	27.9	25.0	16.4	9.3	140
	1-3 Yrs College	18.3	27.9	38.5	9.6	5.8	104
	College Grad.	26.3	26.3	28.8	12.5	6.3	80
	Professional	26.2	33.3	26.2	14.3	0.0	42
E.	AREA OF RESIDENCE						
	Incorporated	23.4	22.3	33.0	13.8	7.4	94
	Rural	41.1	17.9	24.2	12.6	7.2	95
	Urban	20.7	29.9	28.0	14.4	7.1	368
F.	PARTICIPATION						
	Participant	17.6	24.6	34.4	14.4	9.3	148
	Non-participant	28.7	25.8	26.1	13.8	5.5	421

group chose either $1.00 or $2.00, only 57% of those living in incorporated areas chose these answers and only 58% of those living in SMSA's in the state were found in these categories.

Our last control variable was the *recreational activity level* of the respondent. "Beachers" checked the $2.00 fee most frequently, while those who had not gone to the beach during the previous year chose the $1.00 fee-for-use.

Camping. The second "appreciative" category was camping (see Table 3). The modal fee our respondents were willing to pay for one day's use of camping facilities was $5.00 and about 55% of our sample checked either the $2.00 or the $5.00 response. Dividing our sample by *income levels* (Table 3-B) shows that the relationship between this control variable and camping fees is direct (i.e., the higher the income level the more a respondent is willing to pay). The modal category for those making less than $4,000 was $1.00, while those making over $16,000 per year chose the $5.00 fee most often.

Our second control variable was the respondent's *occupation* (see Table 3-C). On this particular variable, the modal category for five of the six occupational groups was $5.00, with nearly 40% of the two highest status groups choosing this fee. For this activity most respondents regardless of occupational level clearly preferred the $2.00 or $5.00 fee.

Next we looked at the differences in response to the question by *educational level* (Table 3-D). For those with least education the $1.00 category was most popular, while those with 10 years of schooling and higher indicated that the $5.00 fee was most popular, with over 50% of the highest educational group (those with post-baccalaureate educations) choosing this category.

Turning now to *place of residence* (see Table 3-C), rural people were most likely to choose $1.00 as the amount they were willing to pay for one day's access to camping facilities, while for the two urban categories the modal response was $5.00 per day.

Finally we separated our sample according to whether or not the respondent had participated in the activity during the past year. Both campers and noncampers chose the $5.00 category most often and campers appeared a bit more willing to pay even higher amounts for camping facilities.

Hunting. Our third recreational activity and the first of our two "consumptive" activities was hunting (see Table 4). Most of our respondents indicated that they would be willing to pay a fee of $5.00 for one day's hunting access and almost 80% of our respondents chose either $1.00, $2.00, or $5.00. Controlling for the *income levels* of our respondents revealed that almost 60% of the lowest income group preferred either $1.00 or $2.00, while almost 50% of the highest income group indicated a willingness to pay from $5.00 to $25.00 for a day's access to hunting facilities.

Dividing our groups into various *occupational*

TABLE 5. Amounts respondents are willing to pay for one day's access to fishing facilities (percentages).

	$1.00	$2.00	$5.00	$10.00	$25.00	Total
A. TOTAL	29.6	26.9	26.4	10.5	6.5	673
B. INCOME						
0-3999	39.7	24.8	18.2	14.0	3.3	121
4000-7999	30.2	28.6	25.4	12.7	3.2	126
8000-11999	32.2	29.6	27.6	6.6	3.9	152
12000-15999	19.5	32.9	32.9	8.5	6.1	82
16000+	24.7	27.4	32.9	8.2	6.8	146
C. OCCUPATION						
Unskilled	25.4	26.8	28.2	14.1	5.6	71
Oper	35.9	25.6	23.1	12.8	2.6	39
Crafts	25.0	27.5	23.8	15.0	8.8	80
Clerical	28.9	28.9	28.9	8.9	4.4	45
Man	22.4	29.4	35.3	9.4	3.5	85
Prof	28.3	35.8	25.8	5.8	4.2	
D. EDUCATION						
Under 3 Yrs	63.6	9.1	12.1	12.1	3.0	33
4-6 Yrs.	38.6	42.9	25.0	11.4	2.3	44
7-9 Yrs.	29.5	25.6	24.4	11.5	9.0	78
10-11 Yrs.	28.6	22.9	27.1	15.7	5.7	70
H.S. Grad.	24.0	26.9	29.9	14.4	4.8	167
1-3 Yrs Coll.	27.3	35.2	28.9	6.3	2.3	128
Coll.Grad.	27.4	32.6	27.4	4.2	8.4	95
Profesional	25.0	33.3	29.2	10.4	2.1	48
E. AREA OF RESIDENCE						
INCORPORATED	28.3	31.3	30.3	3.1	2.0	99
RURAL	45.4	20.4	21.3	9.3	3.7	108
Urban	25.6	29.1	28.0	11.4	5.9	457
F. PARTICIPATION						
Participant	28.0	29.3	23.2	14.1	5.4	360
Non-Participant	31.5	24,2	30.0	6.3	8.1	314

strata (see Table 4-C) revealed that for the least skilled category the modal fee was $1.00, while for occupations above that skill level the choice was either $2.00 or $5.00. The highest group--professional, technical and kindred workers--selected the $5.00 category most often.

When *educational attainment* was controlled (Table 4-D), over half of the least-educated group chose the $1.00 category (56.7%), while only a quarter of the "professional" group selected that category. Over 40% of the latter group indicated that fees from $5.00 to $10.00 were appropriate for access, while less than a quarter of the former group selected these levels (23.4%).

The next control variable was *place of residence* (Table 4-C). Rural residents were most likely to select the $1.00 category (41.1% did so), while the two groups of urban residents preferred higher fees for hunting activity (Table 4-F). Here participants in the activity were more likely to select a higher per-day use fee (the $5.00 fee was modal for this group), while for nonparticipants the $1.00 fee was modal.

Fishing. The second "consumptive" recreational activity which we chose for this study was fishing. As may be seen in Table 5, the $1.00 category was the most frequently chosen by our respondents. Fully 83% of our sample chose either $1.00, $2.00, or $5.00 as the amount they were willing to pay for one day's fishing opportunity. Respondents in the lowest *income level* chose the lowest pay category most often (40% indicated $1.00), while those making over $16,000 annually chose $5.00 most often (Table 5-A).

When we divided our sample into *occupational categories* (see Table 5-B), members of the lower occupational groups picked lower fee categories ($1.00 or $2.00) most often, while higher groups preferred either the $2.00 or the $5.00 fee with the two highest status groups--managers and professionals--indicating the $5.00 category most frequently.

Almost two-thirds of the least educated respondents indicated a willingness to pay only $1.00 for fishing access, while the modal category for the more highly educated was $2.00. Only about a quarter of the former group (24.2%) would pay $5.00-$10.00 for fishing access, while almost 40% of the latter group chose these categories.

Almost half of the rural residents in our sample chose the least expensive fee for fishing access (45.4%), while the two urban groups were practically evenly split between the $2.00 and $5.00 categories (see Table 5-C).

Fishermen were most likely to be willing to pay $2.00 for a day's access, while those who had not been fishing in the past year indicated that $1.00 was the best fee (Table 5-F). However, more nonfishermen selected the $5.00 category than did fishermen.

SUMMARY

The data presented above revealed that fee-for-use as a means for supplementing other public-based revenues in the development and expansion of outdoor recreational opportunities proved to be a popular response alternative for members of our sample. Further, responses to this issue were conditioned by respondents' incomes, occupations, educational levels, places of residence, and levels of participation in outdoor recreational activities. The modal amounts which our respondents were willing to pay for access to various activities were, for beach facilities, $2; for camping facilities, $5; for hunting, $5; for fishing, $1. Intuitively these amounts seem to be in approximate correspondence to the fees charged for access to such opportunities by existing facilities. The application of our control variables revealed that fees-for-use are related to the same characteristics of respondents noted with reference to the general issue of fee-for-use.

A Cautionary Note. As with all studies which seek to impute behaviors from attitudes, these data should be interpreted with caution. It is almost axiomatic in the social sciences that attitudes are only one ingredient in the determination of behaviors.[7] This may be especially true when researchers seek, as we have, to investigate fees-for-use. In making a decision concerning willingness to pay for recreational opportunities, a wide variety of different considerations would be made, some of which would be:

1) The nature of the facilities.

2) The availability of alternatives to the facilities and their relative prices.

3) The proximity of the opportunity to the user.

4) The quality of recreational opportunity, etc.

In light of this problem, answers to general fee-for-use questions such as those we asked should be interpreted only in the most general terms.

CONCLUSIONS

In light of the data presented in this investigation, a fee-for-use approach to supplementing public resources in the provision of outdoor recreational opportunities seems to be a viable source of additional revenues. Two situational factors make these findings even more interesting. First, as noted earlier in the paper, current budgetary situations--national, state, and local --suggest that support from these governmental levels for outdoor recreational development may be diverted to other, more pressing problems. This, of course, suggests that additional resources may be necessary to even maintain existing levels of governmental investment in this area. Secondly, the data may even underestimate the levels of support for such an approach since the sample is from Louisiana, a state which has an abundance of outdoor recreational resources, many of which are freely accessible to recreationalists without charge.[8] The same issues in other states may have even greater levels of support from among the citizenry.

[7] See, for example, LaPiere (1934) and Tittle and Hill (1967) for discussion analysis of the interplay of attitudes and behaviors.

[8] Louisiana's abundance of outdoor recreational opportunities, however, has both positive and negative consequences for the state itself since state revenues for the purchase, maintenance and development of these resources have approximately been among the lowest in the country. (Morning Advocate 1975). We tried to minimize the impact of "free" alternatives in the wording of our questions.

BIBLIOGRAPHY

BUTTEL, FREDERICK H., and WILLIAM L. FLINN. "The Structure of Support for the Environmental Movement, 1968-1970." *Rural Sociology,* Vol. 39, No. 1. 1974.

CLAWSON, MARION, and JACK L. KNETSCH. *Economics of Outdoor Recreation.* Baltimore: 1969. The John Hopkins Press.

DUNLAP, RILEY E., and R. B. HEFFERNAN. "Outdoor Recreation and Environmental Concern: An Empirical Examination." *Rural Sociology,* Vol. 40, No. 1. 1975.

GIRTH, HANS H., and C. WRIGHT MILLS. *From Max Weber:* Essays in Sociology. New York: Oxford University Press. 1958.

GRIMES, MICHAEL D., and THOMAS K. PINHEY. *Public Recreational Uses of Private Lands in Louisiana's Coastal Areas.* Research monograph. Louisiana Sea Grant Publication. In press. 1976.

HARRY, JOSEPH, RICHARD P. GALE, and JOHN HENDEE. "Conservation: An Upper-Middle Class Social Movement." *Journal of Leisure Research,* 1 Summer. 1969.

HENDEE, JOHN C. "Rural Urban Differences Reflected in Outdoor Recreation Participation." *Journal of Leisure Research.*

LINDSEY, JOEL L., KAREW W. PETERSON, and ALVIN L. BERTRAND. "Citizen Reception of Coastal Area Planning and Development." Louisiana Sea Grant Publication No. LSU-T-76-001. 1976.

TITTLE, C.R., and RICHARD J. HILL. "Attitude Measurement and Prediction of Behavior: An Evaluation of Conditions and Measurement Techniques." *Sociometry* 30: 199-213. 1967.

WHITE, TERRENCE H. "The Relative Importance of Education and Income as Predictors in Outdoor Recreation Participation." *Journal of Lesiure Research,* Vol. 7, No. 3, pp. 191-199. 1975.

A REVIEW OF FOREST SERVICE RECREATION RESEARCH RESULTS

Elwood L. Shafer[1]

INTRODUCTION

Need for Recreation Research and Development Programs

To cope effectively with the growing number of management problems associated with outdoor recreation, land managers need research and development programs that provide information and management techniques that go far beyond current knowledge. And yet, perhaps no other forest-oriented management activity involving so many people, and so basic a part of our life, has received less attention from qualified investigators and scientists as outdoor recreation. This is not to belittle the research efforts that have already been made. Past research on outdoor recreation indicates a live and growing interest in the field. And, these research efforts represent a good beginning on a large complex task.

While the outdoors has been very much a part of the American past, and making outdoor recreation available to all Americans has long been a concern of the Nation, this problem in recent years has taken on new dimensions. The growing population--with more leisure time and living largely in cities--has created new challenges for recreation resource allocation, planning, and effective development of facilities. These challenges require the support of thorough knowledge and extensive methodology--the products of research.

Forest Service Recreation Research Objectives

The overall mission of the Recreation Research Program of the Forest Service is to provide land managers with improved technology (knowledge and methodology) so they can substantially increase opportunities for, and benefits from, high-quality recreation experiences. More specifically, the program is designed to provide technology. . .

1. To understand *demand* for and the associated underlying benefits and values from forest-oriented recreation.

2. To measure, maintain, protect and augment the *supply* of forest-related recreation environments.

3. To improve *management capabilities* to design the facilities necessary to integrate outdoor recreation supply and demand, to coordinate outdoor recreation supply-demand relationships with other forestry practices, and to enhance the recreational experiences of recreation users.

These objectives are intended to introduce new ideas, new concepts, and new methods of operation for use in the public and private sectors of recreation-resource management.

A SUMMARY OF RESEARCH FINDINGS

Following are some of the important research results that have been accomplished over the last 15 years within broadly oriented assignments of the Forest Service recreation research program. These results have provided needed technology within the three broad categories that underly the program's objectives, namely: *supply, demand,* and *management*--and are reported here within that context. Details concerning any of these items can be obtained from: Forest Recreation Research, U.S. Forst Service, Washington, D. C. 20250, where bibliographies are available upon request.

Supply

1. Guides to minimize the detrimental impacts of recreation use on the ecology of various environments.

2. The concept of recreation carrying-capacity as it is interrelated with management objectives, visitor attitudes, use perceptions, and impacts of recreation use on the resource.

3. Methods for measuring the environmental impacts of planned, concentrated-recreation developments.

4. A field procedure to measure the impact of visitors on soils and vegetation in wilderness areas.

5. Specifications for the design and layout of wilderness campsites.

6. Inventory methods to assess, monitor, and manage environmental impacts at dispersed recreation sites.

7. Ecological management procedures to maintain or restore original plant communities in wilderness areas.

Demand

8. Typologies for grouping recreation activities when analyzing recreation demand.

9. Procedures for forecasting recreation participation.

10. Models for measuring scenic preferences.

11. Formula for predicting market areas of recreation activities.

12. Descriptions of size, growth rate, and growth potential of the camping/recreation-vehicle market.

13. Analyses of the camper's buying patterns, purchasing behavior, and perceptions of camping.

14. Factors related to enterprise success in the campground industry.

15. Trends in camping participation and camping style.

16. Nature and extent of dispersed recreation on forest roads.

17. Use patterns in wilderness recreation environments.

[1]United States Forest Service, Forest Environment Research, Washington, D.C.

18. Socioeconomic characteristics and attitudes of wilderness users.

19. Importance of solitude to wilderness visitors.

20. Factors that influence wilderness solitude.

21. Means to estimate wilderness use where some visitors do not obtain winderness permits.

22. Impacts of reduction in limits of party size on wilderness use.

23. Survey techniques for measuring attitudes of wilderness users.

24. Correction procedures for eliminating biases in length-of-stay estimates of wilderness users.

25. Methods for measuring wilderness use.

26. Methods for measuring use at concentrated recreation areas.

27. Values derived from hunting experiences.

28. Importance to overall hunter satisfaction from killing game.

29. Importance and impact of fishing at roadless high-mountain lakes.

30. Factors that account for fisherman satisfaction.

31. How leasing of private land can help satisfy recreation demands.

Management

32. Methods to increase the effectiveness of forest-environment interpretation programs.

33. Means for deciding when public involvement is appropriate in land use management decisions.

34. Processes for reducing conflict between timber harvesting and landscape aesthetics.

35. Measurements on the reactions of hunters to timber management practices.

36. Procedures for assessing the overall value of landscape.

37. Guidelines for segmenting large forested areas into landscape management units.

38. Definitions of the dimensions and corresponding terminology of landscape planning.

39. Methodologies for determining information about seen areas, slope, and aspect of natural environments.

40. Instructions for growing plants on viewed landscapes.

41. Designs for increasing amenity values of urban wildlife.

42. Explanations of how to inventory hazardous trees in recreation areas.

43. Comparisons between the manager's and recreationist's perception of resource management problems.

44. Statistics on the extent of the recreationist's membership in conservation groups.

45. Effectiveness of Forest Service public-involvement efforts regarding recreation management decisions.

46. Procedures for analyzing the content of public opinion about resource management issues

47. Ways to control litter, nuisance activity, and vandalism.

48. Means to reduce costs of litter control.

49. Approaches for developing more effective wilderness-management planning guides.

50. Systems to explain the probable distribution of wilderness users throughout an entire network of trails.

51. Simulation models that predict the effects of changes in wilderness use patterns on the number of different encounters, and, thus, solitude that a recreationist will experience.

52. An attitude scale that rates the degree to which a person's basic wilderness orientation agrees or disagrees with fundamental wilderness attributes and values implied by the Wilderness Act.

53. Reaction of wilderness users to rationing of wilderness use.

54. Opinions of wilderness visitors about the use of fire to manage wilderness ecology.

55. Procedures for tabulating data on dispersed recreation use so that data will be of most value to management decisions.

56. Principles for the layout and design of wilderness campsites to protect the quality of the wilderness resource.

57. Analytical models of travel behavior for dispersed recreation activities.

58. Techniques to calibrate records from self-registration stations in wildland areas.

59. Methodology to simulate and predict traffic flow in road networks of recreation areas.

60. Inventory processes for knowing the condition and use of each recreation site in the National Forest System as well as forecasts of future leisure environments.

INTERPERSONAL BEHAVIOR IN CITIZEN INVOLVEMENT WORKSHOPS

D. Q. Brodie and Susan F. Taylor[1]

INTRODUCTION

In the fall of 1974, The Denver Service Center of the National Park Service along with the States of Tennessee and North Carolina conducted citizen participation workshops in the counties bordering the Great Smoky Mountain National Park. Their purpose was to allow citizens to formulate through interaction among themselves a clear statement of their goals and priorities for the region. Planners for the park and local jurisdictions were interested in a reading of the concerns of the *general* population of the Great Smoky region. A problem that in the past had seemed to accompany voluntary citizen participation was that meetings were attended and dominated by a few persons with strong views so that the opinion of a cross section of the public was not obtained. Therefore, for this planning project a model for general citizen participation workshops was developed. The rationale and procedures used form part of this presentation.

The research question to which this paper is directed lies in the nature of the interpersonal behavior of the citizens during the participation workshops. A particular group process was selected to maximize the contribution of all citizens and minimize the influence of any one individual. What were the interpersonal dynamics in the groups? What kinds of group participation were observed? Were there individuals or factions who unduly unfluenced the workshop results? These are the questions to be answered.

Finally, the analysis seeks to demonstrate that the group process selected for this program of citizen participation can reduce the dominance of particular interests in a participation setting. Further, we will show that the observation techniques employed provide quantitative data on the subjective impressions of the observers leaving a lasting record of the proceedings for future reference and comparison.

METHOD

We prepared a citizen participation plan with three goals in mind. First, we wanted to obtain a cross-section of citizens. Second, we wanted to maximize the participation of all participants and avoid the domination of any individual participant. Third, we wanted to be able to analyze systematically the interpersonal behavior that accurred to determine if the desired results had been obtained.

To develop of citizen participation program which would meet these three requirements, components were borrowed from the general areas of sampling, planning and social psychology. First, to insure that a cross-section of citizens attended the workshops a random sample of citizens in each county was selected. This procedure guaranteed that everyone had an equal probability of being selected for participation. Second, a group process technique was chosen, the nominal group technique, which promised to maintain high overall participation during the workshops themselves.[2] Delbecq and Van de Ven (1972:338) have described a nominal group process as a "structured meeting which seeks to provide an orderly procedure for obtaining qualitative information from target groups who are most closely associated with a problem area." Delbecq and Van de Ven report this process to be superior to other group problem identification methods in terms of generating a higher quantity, quality and distribution of critical problem dimensions for problem exploration tasks.

The third component of the process comes from Robert F. Bales' observation techniques for rating interpersonal behavior (Bales 1970). An analysis of a large body of empirical data gathered on small group interaction provided Bales with a set of Types of Group Roles. These are 27 general behavior modes that appear in group interaction. The types are described in terms of three basic dimensions of behavior in groups determined by Bales through factor analytic techniques. The dimensions; upward-downward, positive-negative, and forward-backward refer to an individual's assertiveness and self confidence, his emotional orientation toward the group and his degree of self-orientation. These dimensions taken singly and in combination create the types of group roles. They are not personality types, but interpersonal behavior types. An observer of a group can perform the ratings of interpersonal behavior during and after the group process. This provides for analysis a Bales group type designation for each individual participant. This information can be used to describe the kind of participation that occurs in a group. Because each individual has a numerical ranking on each of the three dimensions, his position in the group can be graphed and the pattern of group relationships can be examined. Therefore, the observer ratings of interpersonal behavior will provide the basis for analysis in this paper.

PROCEDURES

The procedures used to conduct the group workshops involved three distinct sets of activities; the selection of participants for the workshops, the training of group leaders and observers, and the actual conducting of the workshops themselves.

Selection of Participants

Two categories of participants were identified to participate in the group workshops; elected officials from each of the 13 counties in North Carolina and Tennessee which border the Great Smoky Mountains National Park, and private citizens from each of these same counties. In order to insure that a representative cross-section of citizen's concerns be presented at the workshops, we randomly selected citizens from each county. The random selection was achieved by generating random telephone suffixes for the predetermined prefixes for each county. Potential participants

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[2]The authors and other members of the University of Denver CPSU extend their appreciation to Mr. Charles F. Riebe for his considerable effort and insight in selecting a group process.

were contacted by telephone and asked to attend a scheduled workshop.

Training of Group Leaders and Observers

Group leaders and observers were selected with the cooperation of the University of Western Caroliner and the University of Tennessee from among the respective student bodies.[3]

A one and one-half day training session was conducted for all group leaders and group observers.[4] Group leaders were trained in the procedures of the nominal group process including practice in leading mock workshops. Group observers were trained in the use of the Bales Interpersonal Rating form. This form consists of a list of 26 questions concerning group participation and style to be answered by the observer for each individual. Group observations were conducted until a high degree of reliability among the observers was reached.

Conducting the Workshops Themselves

Workshops were conducted during the evening hours at a central location in each county. The data analyzed in this paper are the group interpersonal rating forms collected from the observers at the workshops.

After all participants arrived they were randomly assigned to groups ranging in size from four to eight persons. As each group began the procedures for conducting the nominal group process were followed.

1. Introduction: Each participant received the stimulus question to which he responded by listing his major concerns.

2. Idea Generation: Each participant spends 15 minutes independently writing as many concerns as he can generate. No interaction among participants is permitted.

3. Consecutive Listing of Ideas: At the end of the 15 minute idea generation period each person is asked to share one item from his list. This continues around the group until all lists are presented. New items are frequently generated and these are also presented.

4. Serial Discussion of Ideas: A 30 minute discussion period now occurs. The purpose of the discussion is to clarify, defend or dispute individual items on the list. New items may be added.

5. Break: A 15 minute break follows the discussion period.

6. Ranking Priorities: After the break each participant is asked to select the 10 most important items from the total list. They are then asked to rank these 10 items from most critical (10) to least critical (1). Each person in the group then presents his ranking of items to the others. All rankings are presented and tallied so that a group ranking is created.

7. Discussion: After each person has presented his ranking a spontaneous discussion follows. During this time participants re-clarify, defend, dispute and elaborate the rankings.

8. Re-ranking and Rating Priorities: All participants are then invited to reselect the 10 most critical items and to rate them from most critical (100) to least critical (0). The sums of these rankings for each item represent the group priorities.

DATA ANALYSIS

Figure 1 shows the position of the members of an illustrative group plotted on a two-dimensional graph of the interpersonal rating space as seen from the backward position, looking forward. This perspective enables us to see the relations of members in the dimensions upward-downward and positive-negative.

Briefly, the upward-downward direction represents the relative power of each member as viewed by the observer and other members of the group. The positive-negative direction represents the person's affectiveness orientation, that is, his relative expressive, emotional position. The forward-backward direction locates the person with regard to his task-orientation.

Based on the observers ratings, shown in Table 1, each person in the group is located in a three coordinate space. For example, in Figure 1, individual "C" is located as a UP group role type having a score of 3-upward, 7-positive, and 0-forward (3U, 7P, 0F). Bales characterizes this group type as one who is viewed by other group members as socially extroverted, ascendant, that is upward in the power direction, but at the same time open and friendly. He encourages others to interact to express themselves and give their opinions, but he is neither clearly for the group task nor against it. He seems to be trying to move toward social success and popularity.

Individual "A" is located in 2U, 8P, 3F being a group role type designated PF. The upward direction is dropped here because Bales determined that any difference less than three was not significant. This type would be characterized by group members as agreeable and friendly, task- and value-oriented. He responds to task-oriented others, but does not take the initiative. He is not submissive, however, nor is he ascendent, but equalitarian. He is supportive of the group without being dominant or submissive.

Individual "F" is located in the positive direction having coordinates OU, 8P, 1B. He is a group role type P. This person appears friendly, sociable and informal. He approaches others as equals, neither ascendant nor submissive. He is not concerned with either their task-relevance or status.

Group role type PB is reflected in individual "B" with coordinates OU, 7P, 3B. He is friendly and receptive to jokes, neither ascendant nor submissive. He is not task-oriented, but responsive to others as individual persons.

Person "E" is also a role type PB having coordinates 2D, 6P, 3B. As viewed from the group his role is similar to individual "B".

The last individual, person "D", is located in the downward, positive, backward part of the

[3] Dr. Steve Webster at the University of Tennessee and Drs. Joseph Bassett and Dick Berne at the University of Western Carolina handled all student recruitment. They served as field coordinators for all data collection.

[4] The training sessions were done at the University of Western Carolina by the University of Denver CPSU under the direction of Dr. R. F. Falk.

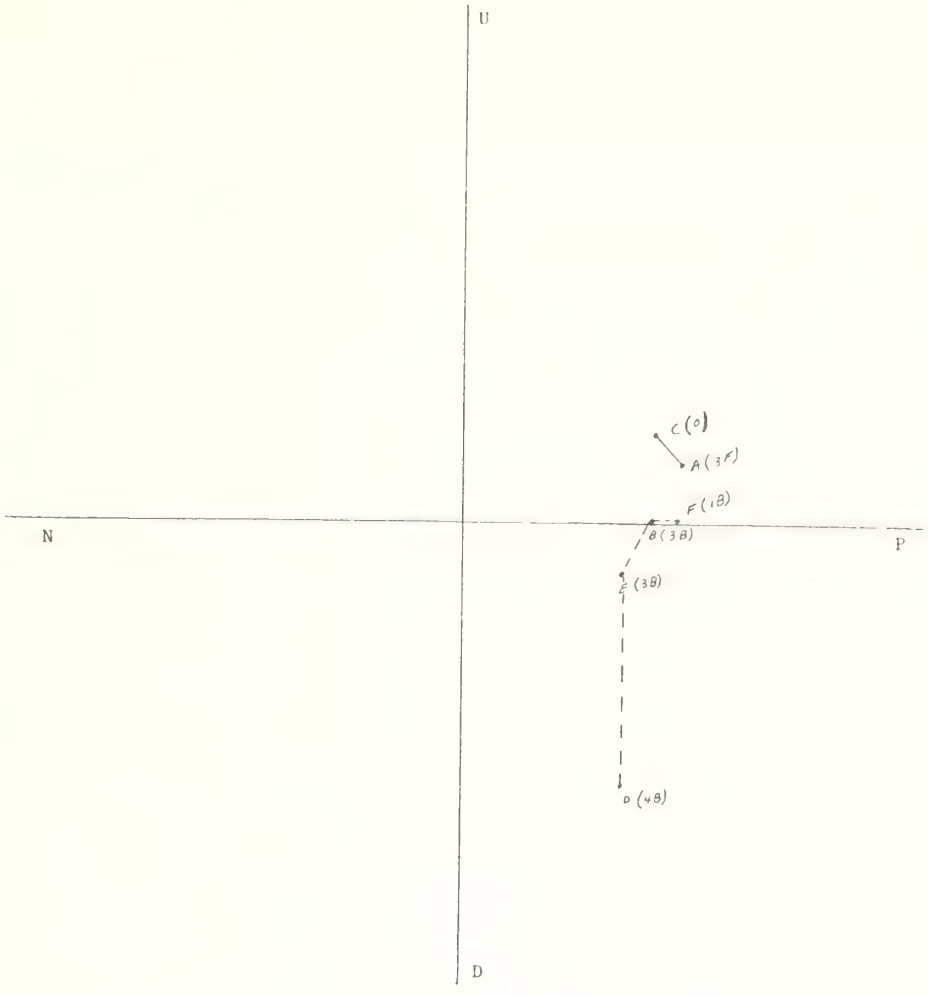

FIGURE 1. A spatial model of group structure.

TABLE 1. List of group members with positions in the evaluative space.

Member Identification	Tabulation For Each Direction	Summary Position	Summary Type
A	10U, 13P, 10F, 8D, 5N, 7B	(2U8P3F)	UPF
B	8U, 11P, 6F, 8D, 4N, 9B	(0U7P3B)	PB
C	10U, 12P, 8F, 7D, 5N, 8B	(3U7P0B)	UP
D	4U, 10P, 5F, 14D, 4N, 9B	(10D6P4B)	DPB
E	6U, 9P, 5F, 8D, 3N, 8B	(2D6P3B)	PB
F	8U, 12P, 7F, 8D, 4N, 8B	(0U8P1B)	P

group space (DPB) and has coodinates 10D, 6P, 4B. As viewed by his fellow members he seems friendly, and nonassertive, quite passive, wishing to receive acceptance. He is not at all task-oriented, but is responsive to the help of others and expectant of receiving what he needs without achievement.

Having described the individual group role type we can now examine the relationship among the group members. Bales has set forth a set of assumptions that allow us to connect into networks or coalitions persons in the group who meet them. First, each person can be thought of as wishing to maintain his movement and the movement of others as far as possible in his own value-direction. That is, he would like others to perceive, feel, think, and act as he himself does. If the individual looks for cooperation or alliance with another, Bales suggests that he will identify with or ally himself with the one other person who is closest to his position, provided that person is further

upward in the power structure. If there is no person close enough, the given person will remain an isolate or may be the terminating upper member of a network. This presents the question of what determines whether individuals are close enough. Bales presents empirical evidence for accepting the distance equal to 58% of the total possible score on any dimension. In this case, this distance is 10 units. Therefore, the procedure for determining coalitions or networks is to begin with the lowest position in the group space and connect upward to the one next closest role type continuing this process until all possible connections are made. This process may produce networks in the forward and the backward direction. The solid line in Figure 1 represents connections in the forward space, the dotted line, connections in the backward space.

Looking at the illustrative group, person "D" is eight units from individual "E" which is close enough to be connected. A connection is made from "E" to "B" over two units. The connection from "B" to "F" completes the possible network of four individuals in the backward space. The distance to individual "A" in the forward space is close enough to connect the pair "A" and "C" to the downward-positive-backward network.

What then does this diagram tell us about the nature of the participation in the group? First, it is apparent that no individual was isolated from group participation. Second, no person occupies a group role type which is characterized by dominating the group interaction. The potential group leader is the highest position in the upward direction, in this case person "C", a UP group type. The UP type is not likely to be a dominating influence, he is socially self-confident, but not task oriented.

It is not possible to present all the individual group diagrams here. Nevertheless, the illustrative group gives us a basis for summarizing the characteristcs of the other citizen group members and the comparative relationships in the groups.

This study includes data on 18 groups, 11 citizen groups and 7 elected official groups. The groups ranged from four to eight members. Of the 101 individuals observed in the groups, 30% were located in the upward-positive-forward space, that is, UPF's. The next largest group of individuals were UF's, 13%, followed by UP's at 10%. Thus, 50% of the participants fell generally in the space characterized by sociability, friendliness, task-orientation and taking the initiative in participating. A large group, 15%, are located in the P, PF, and PB directions which indicates emotional support, task-support, and sociability. Finally, 20% of the individuals are distributed in the directions associated with the downward dimension--DPB, DF, D, DN, DP, DPF. These positions are all participatory, nonassertive, some are task-oriented, some are not, and some are more friendly than others.

It is important to note for our purposes in citizen participation the types of group roles that did not appear in this analysis. There were none of the following positions noted: rugged individuals, individual isolationist, rejecting social conformity, failure and withdrawal, withholding cooperation and self-sacrifice (according to Bales' categories).

To complete our analysis of the relationships within the groups we need to examine two kinds of group role positions--isolates and potential leaders. In the 18 groups all the participants were close enough to be connected into one network per group with the exception of five individuals. What types of group members were these isolates? They were all different types. One was downward-negative, a position representing unfriendliness, self-consciousness, and unresponsiveness, but four others were generally friendly, nonassertive, and non-initiating. This is not a large percentage of isolates among the groups.

Finally,what were the characteristics of the persons in the highest upward position in each group, those that are designated by Bales to be in the leader position? The top positions of the group were fairly evenly divided among the upward group role types--UPF (22%), UP (11%), UF (28%), U (17%), and UNF (11%). These roles vary from cooperative, task-oriented leaders (UPF) to non-task related dominant persons (UP) and autocratic authorities (UNF). Two groups had no clear leaders. None of the types represent aggressive, influencing forces as leaders (UN). Further, no workshop as a whole was dominated in all of its sub-groups by the same kind of group type. Therefore, we conclude that this group process did reduce domination by any faction or individual.

SUMMARY

The research reported in this paper presents evidence that citizen participation workshops conducted in conjunction with a major regional planning effort were successful with regard to the process by which the citizens were involved. That is, the frequently voiced consideration that even citizens who attend public meetings do not participate and that some individuals who attend dominate the group or form coalitions that dominate the group, did not occur in this instance. Rather, the evidence suggests that all who attended the 18 citizens participation sub-groups did participate and no individual or faction dominated the groups.

Based upon these findings we conclude that the group process used in the workshops--the nominal group technique--was successful in producing participation and minimizing group domination.

Finally, we conclude that the use of group observers to collect data on individual and group characteristics is a highly desirable feature to assess any group process. The data collected provide a criterion by which groups outputs can be evaluated and a lasting record of observer impressions.

LITERATURE CITED

BALES, ROBERT F. 1970. Personality and interpersonal behavior. New York: Holt, Rinehart, Winston.

VAN DE VEN, ANDREW, and ANDRE DELBECQ. 1972. The nominal group as a research instrument for exploratory health studies. American Journal of Public Health. (March)

YOSEMITE NATIONAL PARK PLANNING: COMPUTERIZED DATA RETRIEVAL AND ANALYSIS

Gregory Schalliol, Margaret Morgan,
John Reynolds, Robert Schiller, and Thomas Fake[1]

BACKGROUND

In January 1975, the Yosemite General Management Plan Team members met to outline system requirements for managing and analyzing the existing natural resource data of Yosemite National Park to be used in formulating a General Management Plan. Once the information requirements had been defined, the team requested from Data Systems Division, NPS, WASO, a recommendation for the most appropriate data storage, retrieval, and analysis system to use for the Yosemite Plan. After extensive study, the Data Systems Division recommended the establishment of a general purpose cartographic system within the National Park Service to meet the needs of the Yosemite General Management Plan Team and similar planning projects that continually arise in the Service. To implement this recommendation, the Data Systems Division undertook an analysis of existing computer cartographic systems nationwide to identify that system most capable of meeting NPS planning needs. This analysis culminated in the purchase of a package of computer programs from the Computer Research Corporation of Arvada, Colorado, the acquisition and modification of two program packages used by the U.S. Forest Service, and the writing of a number of original programs by the Data Systems staff. The resultant computer cartographic system established within the Service for the Yosemite General Management Plan has been named TIGRIS, an acronym for The Interactive Graphic Resource Information System. TIGRIS is presently maintained by the staff of the Data Systems Division and is available for use for any National Park Service application.

THE COMPUTER AS A TOOL IN THE YOSEMITE GENERAL MANAGEMENT PLAN

At the outset of the Management Plan process, the Yosemite Team was faced with the problem of how best to integrate the large volume of available information describing the resources of the Park to assist them in plan formulation. There were over 80 separate maps describing the significant resources in the Park that needed to be considered in the planning process. To combine and quantify the information on these maps using traditional manual methods would have been extremely difficult and time-consuming. In order to use the TIGRIS system for performing these task, each of the original Yosemite maps was converted to a computer-readable form through a process called "digitization." This process involves tracing lines on the map with a stylus while it is mounted on an electronically sensitive table, or digitizer. As these lines are traced, a series of coordinate X, Y points are sensed and recorded on magnetic tape in conjunction with textual information describing the attributes of the line that has been typed in earlier. The information on magnetic tape from all the digitized maps is verified, corrected, and then stored in the computer in the form of a data base from which information can be retrieved, displayed, and/or recombined in a variety of ways. The Yosemite data base is presently stored in an IBM computer operated by Boeing Computer Services in McLean, Virginia. Access to the data base is attained via standard telephone lines from a cathode ray tube terminal, which is located at the Denver Service Center with the Yosemite Team. This graphics terminal acts as both an input device from which commands can be entered to the computer and an output device on which textual or cartographic information can be displayed to the planner. With the graphics terminal and the TIGRIS software, the planner can "interactively" draw cartographic displays on the screen and preserve the results using a hard copy device attached to the terminal. "Interactive" operation means that commands given to the computer are executed as soon as the computer has the resources available to fulfill them. Thus, maps from the data base can be drawn on command to the terminal, making the terminal essentially a mechanical cartographer at the fingertips of the planner. Full-sized drawings are produced by outputting map-defining data to magnetic tape, which then drives a large mechanical plotting device. Finalized drawings on the plotter can include a variety of colors, line widths, and materials.

The first major resource analysis problem facing the Yosemite Team was to locate those areas in the Park, particularly in the Yosemite Valley, that were most favorably adapted to certain types of land use. For the Valley, the Team needed to locate those areas most suitable for campgrounds, picnic areas, man-made structures, unpaved roads or parking areas, and paved roads or parking areas. In conjunction with the Park staff, the Yosemite Team decided which resources in the Park, such as soil and vegetation types, should be present at any location where, for example, a campground was to be placed, and also those resource characteristics in which a campground should not be placed, such as areas prone to avalanches or rockfalls. A set of positive and negative criteria like this for each of the five land uses was developed by the Team and entered into the TIGRIS system. By then executing the proper sequence of programs, the composite map (Figure 1) was produced. This is the structures suitability map for Yosemite Valley produced by the TIGRIS system. It meets all the resource characteristic criteria decided upon by the Yosemite Team. It is a composite map which includes over 16 overlaid variables from the original data base. The areas most suitable for structures, that is, those areas which include all of the positive criteria and exclude all of the negative criteria, are the unshaded areas on the map. To highlight undesirable areas on this map, they have been shaded to simulate the McHarg overlay technique. Similar suitability maps were produced defining the optimal locations for campgrounds, unpaved vehicle parking areas, paved vehicle parking areas, and picnic areas. Production of these maps using manual cartographic procedures would have required an enormously large number of additional person-hours, many provided by the planners themselves. The use of the TIGRIS system by the Yosemite Team allowed

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FIGURE 1. Areas suitable for structures, Yosemite Valley.

FIGURE 2. Yosemite Valley from Wawona Tunnel entrance.

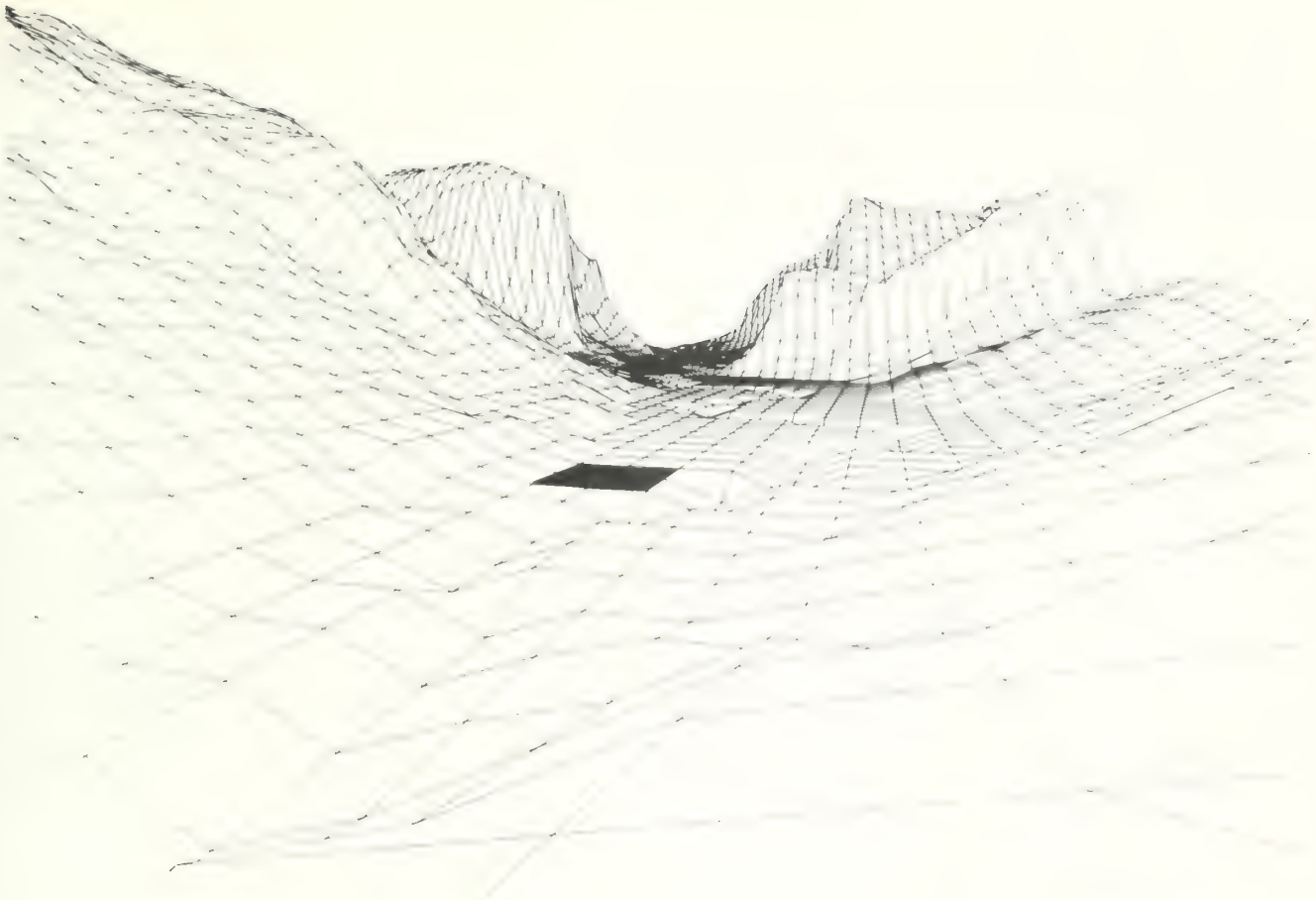

FIGURE 3. Computer perspective of Yosemite Valley from Wawona Tunnel entrance.

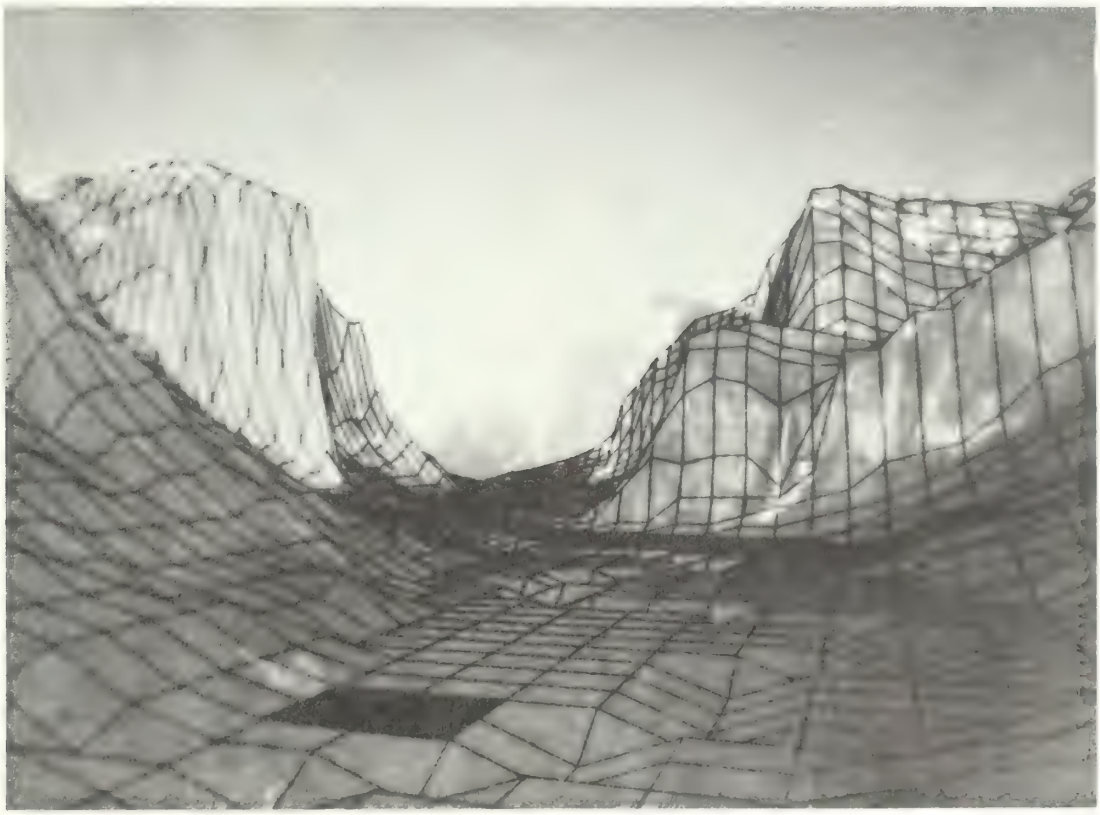

FIGURE 4. Combined photograph and computer perspective of Yosemite Valley from Wawona Tunnel entrance.

Team members to spend more time performing planning tasks while the computer performed the more menial tasks of map overlaying, data combination, and shading.

A second major problem facing the Yosemite Team was the quantification of areas on the maps for a precise description of the resources in the Park. Traditionally, to obtain acreage estimates from a map the planner has had to either overlay transparent gridded paper on the map and count cells of a specified size included within the area of interest or to trace around the perimeter of the area with a planimeter. Both of these procedures are extremely time-consuming and afford limited accuracy. Their use would not be feasible for doing a large number of determinations from several complex maps, nor for quantification to the level of detail the Yosemite Team requires. The computer, however, can calculate the acreage of a closed area very rapidly with accuracy limited only by the degree of precision of the digitized data. The Yosemite Team has used TIGRIS frequently to compute the acreages of areas on maps of the Park. In those cases where acreage values were required for areas not previously digitized, the Team members used another device integral to the TIGRIS system: the digitizing tablet. The digitizing tablet is permanently connected to the graphics terminal and essentially a small version of the digitizing table shown earlier that was used for originally transforming the maps into a computer-readable form. The planner can communicate directly with the computer from the tablet, allowing the creation of new cartographic information which can be added directly to the data base. In order to compute the acreage of previously undelineated areas, the planner need simply outline the area of interest on an existing map, place it securely on the tablet surface, orient the tablet coordinate system with two simple commands, and then trace around the outlined area with the stylus. The acreage calculation is then completed by the computer and the new cartographic polygon can be either stored in the data base or discarded.

In these ways, the use of TIGRIS has allowed the Yosemite General Management Plan Team to accurately quantify the characteristics of a large number of the natural resources and man-made features in the Park which previously were either only poorly estimated or completely unknown. The computer again acts as a timesaving device, enabling the Yosemite Team to obtain more needed information in a shorter amount of time.

A third major problem facing the Yosemite Team was determining the visual impact of proposed parking areas in the Valley. Yosemite, as most other National Parks, has experienced a tremendous increase in automobile traffic over the past several years. To accommodate this change, a number of proposals have been made for constructing new parking facilities in the Valley. Because of the importance of maintaining the beauty of Yosemite Valley, it was necessary to closely examine the visual impact that alternative parking structures would have as seen from the popular viewpoints overlooking the Valley. To assist in this visual impact analysis, the Yosemite Team used the three-dimensional-perspective-plotting portion of the TIGRIS system. From a two-dimensional matrix of elevation data points, the TIGRIS system can generate a three-dimensional perspective representation of the topography in the area from any viewpoint selected by the user. As an example, an actual photograph of Yosemite Valley as viewed from the Wawona Tunnel entrance at the west end of the Valley is contained in Figure 2. Figure 3 is the same view as generated by the three dimensional perspective drawing program in TIGRIS. The Merced River has also been lowered below ground level to show its location in relation to the rest of the features in the picture.

The darkened area on the drawing was drawn in by hand to show the location of an area considered for parking. With this location highlighted, the Yosemite Team obtained an indication of how visually prominent a parking area in this location would be from the tunnel viewpoint. Figure 4 combines the preceding two figures to illustrate the accuracy of the computer-generated perspective.

The work of the Yosemite Team in these three well-defined problem areas:

- Suitability Analysis
- Resource Quantification
- Visual Analysis

has been profitably enhanced by the use of the TIGRIS computer graphic system. In addition to these areas, the Yosemite Team has frequently used TIGRIS for rescaling maps, producing new map copies to replace older and less accurate versions, overlaying several maps for composite map production, selectively retrieving and displaying a number of logically related groups of data from the data base, and for other functions as well. There are a number of other cartographic products that can be created by the TIGRIS system which extend beyond the Yosemite Team's immediate needs. From the same two-dimensional matrix of elevation points used to create the three dimensional perspective drawings we have just seen using TIGRIS, one can also produce:

1) Aspect maps, showing the direction toward which the ground is facing at any point (Figure 5).

2) Maps for either elevation or for slope (Figure 6).

3) Contouring and three dimensional perspective combined in a perspective contour drawing (Figure 7).

4) Seen area maps, outlining the areas which are visible from one or more chosen viewpoints (Figure 8).

Other general mapping options include a variety of letter types, a variety of line types, a standard symbol set for depicting features such as campgrounds, roads, schools, churches, etc., and a number of other useful options that provide a great deal of flexibility in general cartographic production. In each of these areas, the computer can be a reliable and timesaving tool using the capabilities of the TIGRIS system to perform tasks previously performed by the planner. The computer is not a tool which makes independent decisions: it is only an efficient means of analyzing and displaying the information which the planner has decided is important for decision making.

THE FUTURE OF COMPUTER-ASSISTED GRAPHICS IN THE NATIONAL PARK SERVICE

The use of computer-assisted analysis was as extensive and comprehensive in the development of the Yosemite General Management Plan as in any previous planning project the Park Service has undertaken. For this type of application, the results have proven that the computer provides the capability for performing analysis, both statistical and spatial, to a level of accuracy

FIGURE 7. Computer-drawn contour perspective.

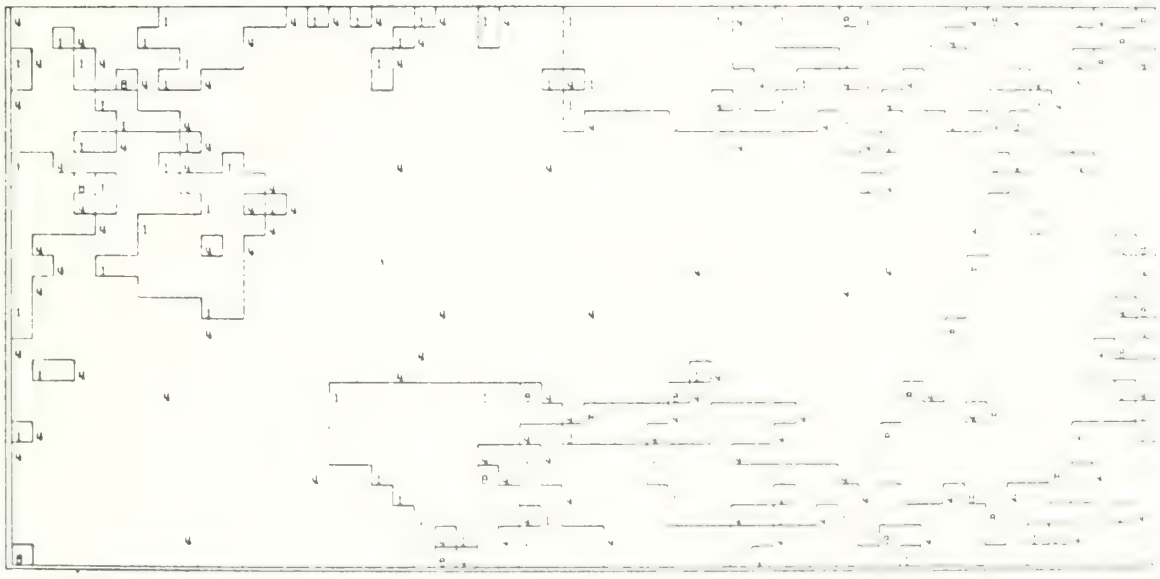

FIGURE 8. Seen area zones from a single viewpoint.

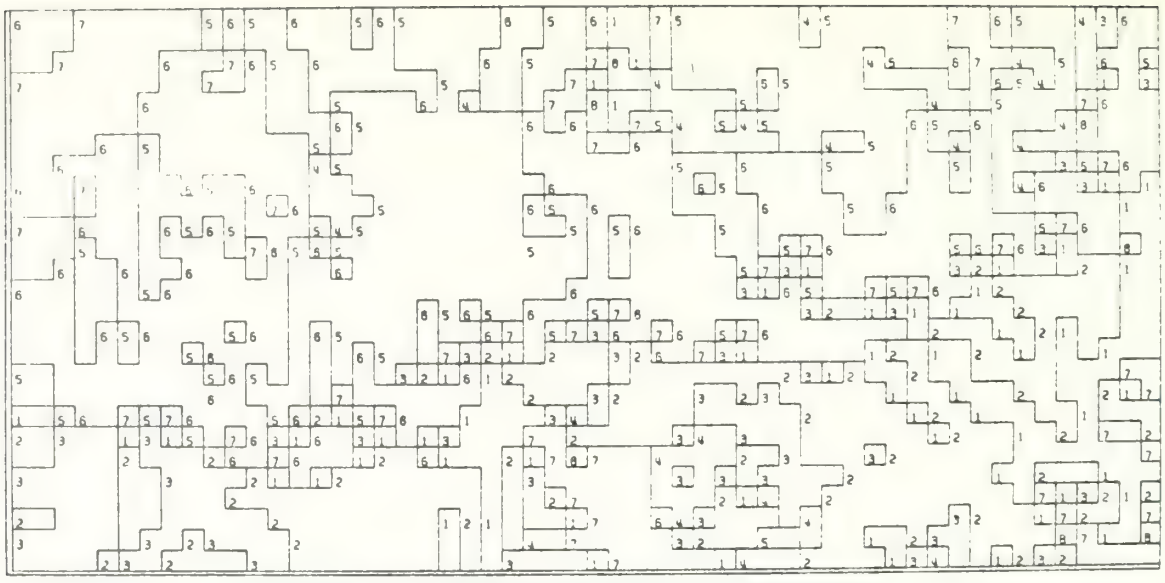

FIGURE 5. Ground aspect in four directions.

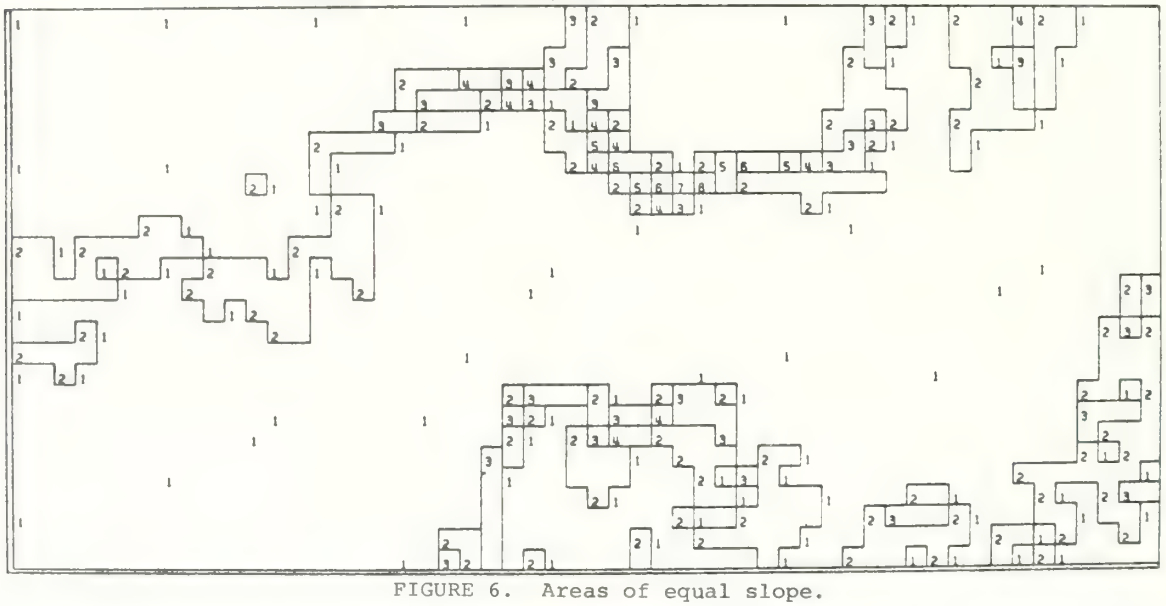

FIGURE 6. Areas of equal slope.

that would be extremely difficult, or in some cases, impossible using the traditional manual graphic and measurement techniques. Of greatest significance, the use of the computer to perform the more mundane functions frees the planner to do those innovative functions that will enhance the final product.

However, as with the implementation of any new technique, new problems arise even though older ones are solved. In computer-assisted cartography, a major difficulty exists in the digitization phase of converting the original maps into a computer-readable form. Digitization is still largely a manual process that takes a great deal of time to do properly. There is a significant time lag between the time source maps are submitted for digitization and the time when the data base is actually ready for use. Only more careful preparation and verification of the original maps and improved technology associated with digitizing will decrease this time lag. Also, as with any new tool, the user must become familiar in its use to be able to obtain optimum results. The additional amount of time required to learn to use the TIGRIS system will inevitably be offset later in the time savings realized in its use.

The TIGRIS system is a dynamic entity, with enhancements and improvements continually being added to meet new Service needs in more efficient ways. The TIGRIS system is presently available for use in any National Park Service project by any Service personnel As computer processing charges decrease, and as the demand for greater accuracy and quantification in park planning increases, the use of computer-assisted graphics within the National Park Service will become more and more advantageous. There is a danger, however, in thinking that the use of a computer will allow us to abdicate the responsibilities for making decisions concerning what information is important, what information we should use, and what products we require. The use of the computer can be effective and successful only after these decisions have been made by the people in the National Park Service.

A CONCEPTUAL BACKCOUNTRY CARRYING CAPACITY MODEL

Jan W. van Wagtendonk[1]

INTRODUCTION

In 1890, when Yosemite National Park was established, few people visited the Park. Fewer still ventured into the trackless backcountry areas. Since that time use has increased many fold; and in 1975, 2,619,042 people visited the Park and 70,902 people spent nights in the backcountry. Approximately 90 percent of the 761,000-acre Park is considered backcountry.

In less than 10 years, backcountry use has tripled while use of the Park as a whole has increased only 15 percent.

Such high levels of use have led to conflicts with the enabling legislation which established the National Park Service and states that the parks will be managed ". . . to conserve the scenery and natural and historic objects and wildlife therein and to provide for the enjoyment of the same in such a manner and by such means as will leave them unimpaired for the enjoyment of future generations." (U.S. Congress 1916). Past management practices have slighted resources protection in efforts to accomodate the burgeoning crowds of visitors.

This has been especially true in backcountry areas where maintenance, restoration and control activities are particularly difficult. Eroded trails, trampled vegetation, polluted streams, and conflicts between users have resulted as the number of backcountry visitors continued to rise.

Increased use and the problems associated with that use warrant the establishment of use limits. Imminent classification under the Wilderness Act of most of the Yosemite backcountry gave additional impetus and a legal basis for limiting use. In order to fully understand the complexities and ramifications of a decision to set limits, a conceptual model was needed.

The Concept of Carrying Capacity

Inherent in any determination of use levels is the concept of carrying capacity. The term has been widely defined but is little understood. Its original use was in the field of range management, where carrying capacity was defined as the number of animals which can graze a given area each year without inducing a downward trend in the forage (Stoddart and Smith 1955). Grazing capacity can be increased by various management practices which either improve the distribution of animals or improve the forage. Crowding is not a part of this definition since cattle appear to have a high tolerance for each other.

Most definitions of recreational carrying capacity include both ecological and psychological factors (Wagar 1964; Lucas 1964). These are best characterized by Lime and Stankey (1971) when they define recreational carrying capacity as ". . . the character of use that can be supported over a specified time by an area developed at a certain level without causing excessive damage to either the physical environment or the experience for the visitor." Any use at all of a wilderness will cause some damage; the problem becomes one of defining excessive damage (Wagar 1974). Frissell and Stankey (1972) used the concept of limits of acceptable change in wilderness ecology and in wilderness experience. What is acceptable becomes a management decision which should be based on legislation, policies and management objectives.

For instance, the Wilderness Act (U.S. Congress 1964) gives broad guidelines for the qualities of a wilderness environment and alludes to the wilderness experience by mentioning that wilderness areas will provide ". . . outstanding opportunities for solitude." Departmental guidelines and agency policies interpret the act and define what activities and services are or are not appropriate (Sudia 1973).

Since management plays an integral role in the ultimate determination of carrying capacities, definitions of carrying capacity should include a provision for management input (Bury 1976). The importance of this management input is stressed by Wagar (1968), when he states that the ecological component of recreational carrying capacity can be increased by manipulating the environment through such means as fertilization, irrigation or supplemental planting. These methods are generally considered inappropriate in areas designated as legal Wilderness, however. The psychological factor of recreational carrying capacity can be influenced by educating, screening, zoning, and regulating users (Lee 1975). Managers, again, must decide which methods are appropriate and must weigh the effects of those methods on the natural resources of the area, on the wilderness experience and on budgetary constraints.

A Comprehensive Approach

In order to take a comprehensive approach to determining recreational carrying capacity, all factors--ecological, physical, psychological, and managerial--must be considered. This means more than simply looking for the most sensitive factor in a particular area and limiting use to that level which does not cause the factor to change beyond an acceptable limit (Bury 1976). Rather, it should be realized that the various values which affect carrying capacity are very complex and interrelated (Lee 1975). A comprehensive approach should provide a means for the manager to optimize the total effect of all the factors of carrying capacity. Such an optimization would produce a combined effect that would maximize values according to selected and weighted criteria (Bury 1976).

The conceptual model presented here attempts to incorporate this comprehensive approach. The model is being used as a basis for a research program for determining use levels for Yosemite National Park. It is a planned approach, which is being developed for application. As research results are synthesized through the use of the model, they will be related to the actual management of a backcountry area.

[1]National Park Service, Yosemite National Park, California.

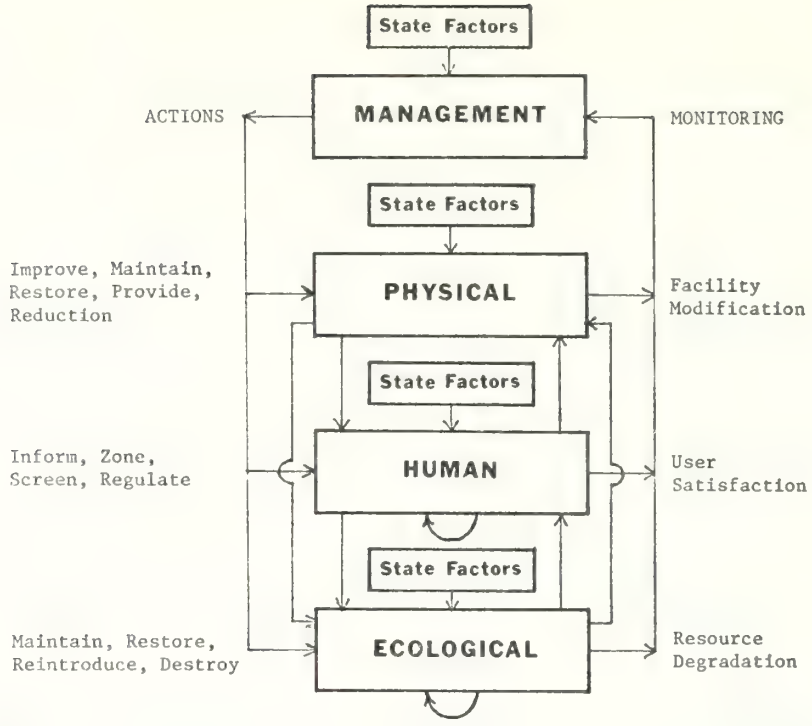

FIGURE 1. Conceptual model of recreation area carrying capacity.

A CONCEPTUAL MODEL

Conceptual models have been developed by Lime (1970), Frissel and Stankey (1972), Stankey (1973), and Lee (1975). The present model combines features from all of these with newly developed ideas and provides a framework for a functional backcountry management system. The model is comprised of management, physical, human, and ecological components (Figure 1). State factors are the independent conditions under which the system operates such as legislation or climate. Effects are measured by changes in the components. These changes are in turn monitored by management to determine future actions.

Components

Management. Lee (1975) describes the management component as consisting of decision makers who monitor the effects of management actions (or the results of no action) on the physical, human and ecological components. Changes in these components are evaluated in the light of objectives and constraints. Such independent conditions as legislation and public opinions and legal, policy and budget constraints constitute the state factors for the management component.

If the evaluation indicates that an unacceptable change has occurred, a problem is identified and management alternatives are sought. The decision maker then assesses the impacts of the various alternatives and makes a decision. This decision results in the allocation or reallocation of funds and personnel to take or not take some management action.

Physical. The physical component is defined as unnatural facilities which are either constructed by management or users. Included would be such facilities as trails, bridges, campsites, hitching racks, tables, benches, fire rings, signs, pit toilets, wells and garbage cans. State factors consist of the existing system of facilities that a particular area might have. Effects on the physical component are manifested in some modification of facilities. Users can affect trails by increasing tread width, causing multiple trails, cutting switchbacks, littering or picking up litter, or using stock which deposit manure. Campsites can be modified by building tables, benches or fire rings. Vandalism can result in the destruction of signs, bridges, pit toilets and other facilities.

Management actions which affect the physical component include the improvement, maintenance, restoration, provision, or removal of facilities. For instance, trail treads can be maintained, multiple trails eliminated, and trail erosion abated. Campsites could be built, improved, or destroyed. Fire ring eradication, litter pickup and vandalism repair are actions which are often undertaken. The conditions of the facilities are monitored by management to determine if they deviate from accepted norms.

Human. The backcountry users comprise the human component of the model. Individuals, parties, parties of different types, and parties of different group sizes are elements of the human component. The independent factors include the background each user brings to the backcountry --his or her education, experience, and expectations.

User satisfaction is generally accepted as one measure of the quality of a wilderness experience. Satisfaction can be divided into overall satisfaction, social satisfaction, physical satisfaction, and ecological satisfaction (Lee 1975). Social satisfaction is affected by the number of people encountered, the number of groups encountered, the size, types, friendliness, and destructive acts of those groups. Trail condition, amount of litter, presence of facilities, amount of manure, and number of fire rings affect physical

satisfaction. Satisfaction with the ecological environment is dependent on the ground cover condition, evident tree damage, water quality, lack of wildlife, and wildlife encounters. Overall satisfaction and perceptions of crowding are influenced in one way or another by the above factors. The quality of the wilderness experience is also measured in terms of the opportunities for solitude afforded and the degree of naturalness present.

The manager has several actions available which can directly or indirectly affect user satisfaction. Information dispersal can be used to attract specific user types or advertise little used areas, instruct users on minimum impact techniques, and change user preferences (Lee 1975). Permits, fees, and skill requirements can be used to screen access to the backcountry resulting in fewer, more knowledgeable users. Zoning areas and regulating numbers are two direct methods managers can use to control use in attempts to maintain user satisfaction.

Ecological. Elements of the ecological component include the vegetation, soil, water, and wildlife of the area. These are dependent on the independent conditions of climate, topography, parent material and available organism pool.

Users impact vegetation by trampling, cutting and carving in trees, and collecting fuel wood. Soils are compacted in heavily used areas and erosion can occur whenever soil is bare. Campfires change the physical and hydrological properties of the soil beneath them and escaped fire can cause considerable unnatural changes to the vegetation. Water pollution is caused by improper human waste disposal, and washing or bathing in streams and lakes. Wildlife is affected in two ways by use. Some species which are sensitive to human presence, such as the wolverine, will decline as a result of increased use. Others, like the black bear and Steller's jay, increase their population levels as unnatural food sources increase.

Resource condition is monitored by management to determine if unacceptable changes have occurred. Such changes would result in ecosystem instability if allowed to continue unabated. If conditions have exceeded acceptable limits, restoration techniques can be employed to return to the desired condition. Meadows can be replanted and extirpated animals reintroduced. Resource maintenance actions might be called for if conditions are such that continued use would eventually lead to unacceptable change. Plant and animal populations which have increased unnaturally in response to human use can also be reduced by management.

Model Dynamics

The conceptual model must be translated into terms which can be used in a computer simulation model before the dynamics of the model can be understood. Several steps are necessary to accomplish the translation. First, relationships between components must be defined and acceptable limits of change determined. The next step is to represent those relationships with model equations. Finally the model is simulated and optimum solutions derived through experimentation and linear programming techniques.

Relationships. Within the conceptual model, relationships occur along the pathways between components. These relationships are characterized by an operator from one component, in combination with independent state factors, acting on an operand of another component to produce an effect.

Figure 2 is an example of some of the possible relationships between the human and ecological components. For instance, a certain amount of backpacking use occurring during the spring, given the topography, parent material, climate and available flora, will affect the vegetation by causing some change in vegetative cover.

Similar lists have been developed for each of the pathways between components in Figure 1. These lists are not meant to be inclusive, but rather a sample of some which are felt to be significant for the Yosemite application. Other variables and other assumptions might be added or changed within the same framework to fit other areas or agency contexts.

The research program has been designed to define the nature of those relationships which are known to be important and for which little or no information exists. Many relationships have been determined and are available in the literature. Running of the model will indicate which relationships are most sensitive and, therefore, warrant additional research efforts.

The results of the research studies will be represented by graphs which relate visitor and management inputs to their impacts. Figure 3 is an example of such a relationship where, as use goes up, impact generally increases. Such a relationship exists for vegetation trampling. Small amounts of use have little effect and the vegetation is able to recover quickly. Increasing amounts of use, however, accelerates deterioration until a point is reached where little additional damage occurs.

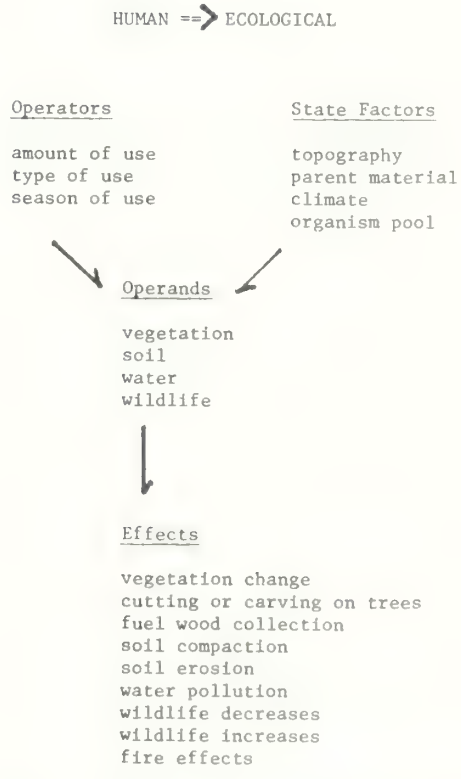

FIGURE 2. Human-ecological relationships.

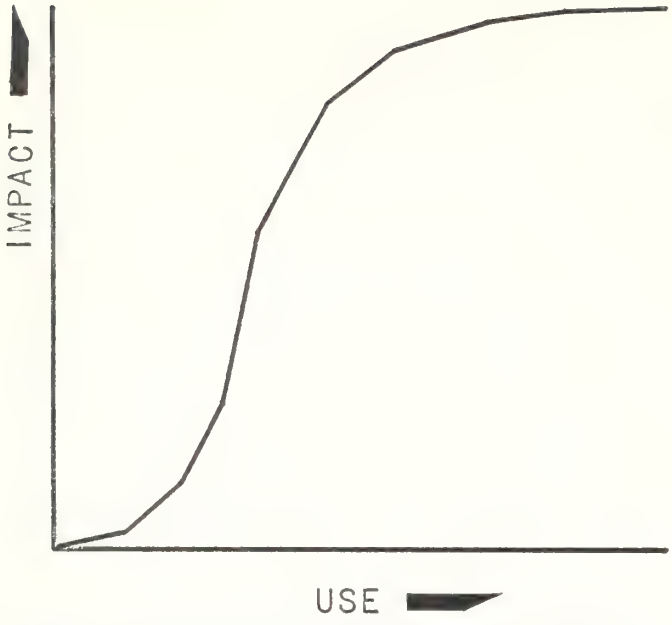

FIGURE 3. Relationship between use and impact.

The relationship between use and encounters is essentially linear where an increase in use causes an equal increase in number of encounters. Since visitor satisfaction is one of the measures of psychological carrying capacity, it is necessary to relate encounters to satisfaction. Figure 4 shows such a relationship where satisfaction drops quickly after a relatively small number of encounters. This relationship varies, of course, dependent on the party, the party encountered, its size and behavior, and the time and place of the encounter.

Management actions are also related to their impacts through the use of graphs. As additional actions are taken to ameliorate or prevent impact (represented by the funds necessary for that action), the impact is assumed to decrease (Figure 5). For example, if more money is spent on backcountry rangers, less impact might be expected to occur by visitors camping in fragile meadows.

Acceptable Limits. Recommendations for the determination of acceptable limits of change will be based on legislative interpretation and research results, as well as knowledge of what is feasible and the trade-offs involved. The final decision should be made in light of all of the ramifications of any specific level of use. Graphs such as those in Figures 3, 4 and 5 will be helpful to the manager in selecting acceptable limits. Points on the graphs where small increases in use begin to result in large increases in impact such as dissatisfaction in Figure 5 are likely limits to acceptable change.

Hard decisions have to be made by managers concerning the level of visitor satisfaction and the amount of resource damage that are to be allowed. Once acceptable limit decisions have been made for each graph, a level of use is specified for the area represented by that relationship.

Model Equations. In order to integrate the model, the various relationships must be expressed by mathematical equations. The dynamics of the model is represented by differential equations of the general form:

d(Component)/d(time)=f(Components, State Factors),

where changes ("d" in the equation) in the components with time, as measured by facility modification, user satisfaction, and resource condition, are functions ("f" in the equation) of component interactions and state factors.

Since digital computers operate with discrete time intervals, difference equations have to be used to express changes in the components. In systems terminology, these equations are called level equations, where the levels express the state or condition of the system at any particular time (Forrester 1968). Levels integrate or accumulate the results of action in the system.

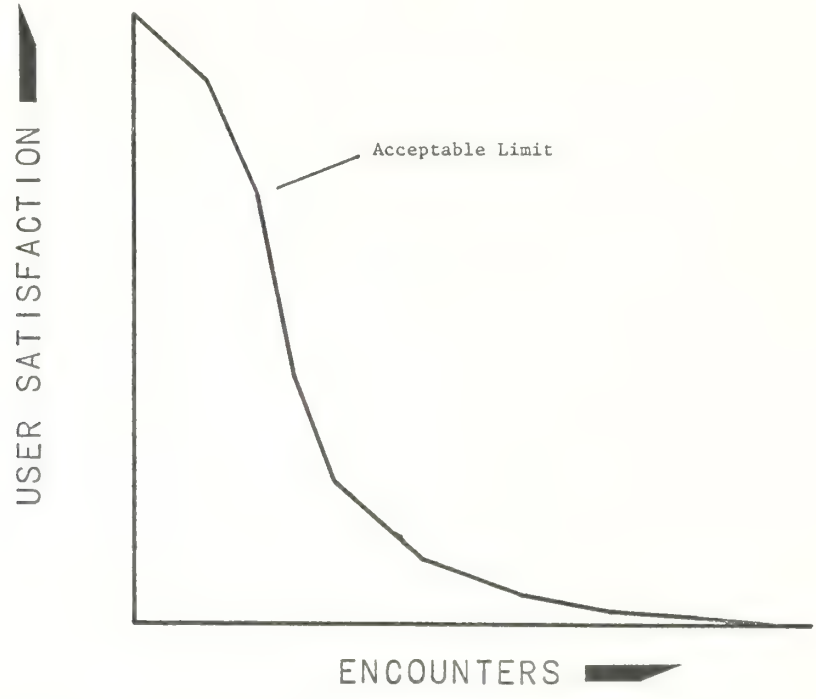

FIGURE 4. Relationship between encounters and user satisfaction.

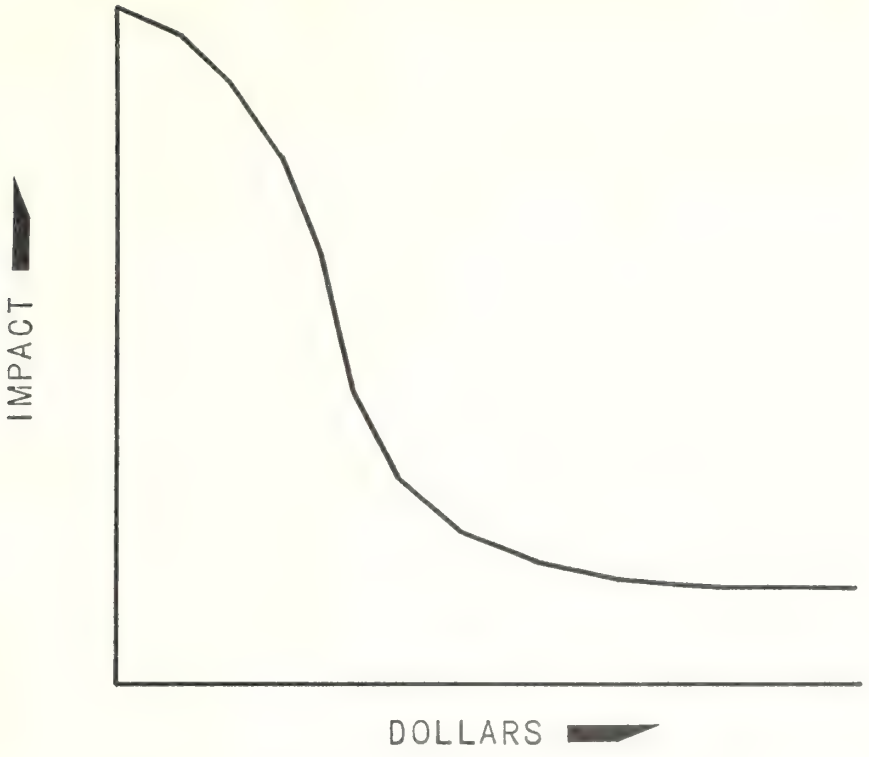

FIGURE 5. Relationship between dollars and impact.

They can only be changed by rate variables which tell how fast the levels are changing. Rate variables depend only on the values of the level variables and constants such as the state factors.

Simulation. Most dynamic behavior in social and ecological systems is so complex that analytical mathematical solutions are impossible. For such systems, only the step-by-step simulation process is available (Forrester 1968). A useful simulation model of the backcountry carrying capacity system should be able to represent the nature of the system; it should show how changes in policies or structure will produce better or worse behavior and impact.

Experimentation with the simulator will allow testing of the acceptable limit assumptions and will indicate which relationships are sensitive to change. For any particular area, several use levels might be indicated by the relationships pertinent to that area. The lowest value could be accepted as the carrying capacity. More desirable would be optimum carrying capacities which can be obtained through experimentation and linear programming. The model equations, along with the state factor and acceptable limit constraints, lend themselves to optimization by this technique. All pertinent relationships have to be weighted to represent their relative importance, and then considered simultaneously to derive the optimum solution.

Outputs from the simulator will be use levels which can be applied to each area of the backcountry. Specific carrying capacities relating to the unique characteristics of each area can be determined for every trail segment, campsite, and travel zone in the Park.

SUMMARY

A conceptual model for relating research-based relationships of variables to the actual management of a backcountry area has been developed. The model forms the framework for understanding carrying capacity, the basis for research studies, and the structure for dynamically integrating the various factors affecting use levels. Relationships between visitor and management inputs and their impact are basic to the model. Management decisions concerning acceptable limits of change identify appropriate use levels. Optimal capacities are set for each trail segment, campsite and travel zone through model simulation.

LITERATURE CITED

BURY, R. L. 1976. Recreation carrying capacity - hypothesis or reality. Parks and Recreation 11(1):22-25, 56-58.

FORRESTER, J. W. 1968. Principles of systems. Wright-Allen Press, Cambridge, Massachusetts. 384 p.

FRISSELL, S. S. and G. H. STANKEY. 1972. Wilderness environmental quality: search for social and ecological harmony. Soc. Am. For. Proc., Hot Springs, Ark. p. 170-183.

LEE, R. G. 1975. The management of human components in the Yosemite National Park ecosystem. Final Research Report. Yosemite Institute, Calif. 134 p.

LIME, D. W. 1970. Research for determining use capacities of the Boundary Waters Canoe Area. Naturalist 21(4):9-13.

LIME, D. W. and G. H. STANKEY. 1971. Carrying capacity: maintaining outdoor recreation quality. For. Recreation Symp. Proc., Northeast For. Exp. Stn., Upper Darby, Pa. p. 174-184.

LUCAS, R. C. 1964. The recreation capacity of the Quantico-Superior area. USDA Forest Service Research Pap. LS-15, Lake States For. Exp. Stn., St. Paul, Minn. 34 p.

STANKEY, G. H. 1973. Visitor perception of wilderness recreation carrying capacity. USDA Forest Service Res. Pap. INT-142. Intermountain For. and Range Exp. Stn., Ogden, Utah. 61 p.

STODDART, L. A. and A. D. SMITH. 1955. Range management. McGraw Hill, New York. 433 p.
SUDIA, T. W. 1973. Recreational carrying capacity of the National Parks. Guideline 3:25, 27-34.
U.S. CONGRESS. 1916. An act to establish a National Park Service, and for other purposes. (39 Stat. 535).
U.S. CONGRESS. 1964. An act to establish a National Wilderness Preservation System for the permanent good of the whole people, and for other purposes. Public Law 88-577.
WAGAR, J. A. 1964. The carrying capacity of wild lands for recreation. Soc. Am. For., For. Sci. Mongr. 7, 23 p.
WAGAR, J. A. 1968. The place of carrying capacity in the management of recreation lands. Third Ann. Rocky Mountain-High Plains Park and Recreation Conf. Proc. 3(1), Fort Collins, Colo.
WAGAR, J. A. 1974. Recreational carrying capacity reconsidered. J. For. 72:274-278.

USE OF A WILDERNESS SIMULATOR FOR MANAGEMENT DECISIONS

Jan W. van Wagtendonk[1]

Once the manager has some idea about the amount and character of use each trail segment and campsite should receive, he or she must have a means to distribute use in accordance with the desired capacities. Several methods are available from allowing the user total freedom of choice to designating fixed itineraries for every party. The effectiveness of each method to distribute use needs to be tested. This could be done by actually implementing a different method each year and comparing the results. This, of course, would take too much time and the results such as long-lasting resource damage might not be desirable. Computer simulation of wilderness area use is an alternative which offers considerable time savings. such a simulator was developed for the U. S. Forest Service by Resources for the Future.

The Wilderness Use Simulation Model was originally developed to estimate use patterns in the future under alternative management strategies (Schechter 1975). The simulator can be used with relevant data for any wilderness area and its conditions. The results are a measure of the impact of both use and management on the wilderness resource experience. Management actions are tested by using various scenarios on the simulator.

INPUT INFORMATION REQUIREMENTS

Certain information is needed about a wilderness area and its use before the simulator can be run. Specifically, descriptions are needed for the trail network, characteristics of the users, and the way that the users interact with the trails.

Information Sources. A wilderness permit system has been in effect in Yosemite since 1972. From this permit, information is gained on party types, party size, and user arrival patterns. The information necessary to determine party routes is also on the permit.

In order to determine the reliability of the permit data, compliance checks were made. It was found that 87 percent of the parties had a permit. In addition to checking compliance, the routes of parties without permits and route changes for parties with permits were determined.

The simulator requires that routes be described by trail segments rather than by the travel zones which are on the permit. Programs have been written to take the string of travel zone and trailhead numbers of a particular party's trip and translate it into trail segments and campsites. This is done for party types, party sizes, and times of the year.

The description of the backcountry trail and campsite system was determined from maps and field investigations. Each trail segment was measured for length and delineated into slope classes. Parties were timed over a sample of trail segments of varying steepness in order to assign transit times for each trail segment of the park. Horse party times were .78 as long as hiking party times, but there was no significant difference between times of different party sizes.

If it is desired to obtain information concerning visual encounters, a list must be made for each trail segment and campsite for those segments and sites which can be seen from the other. This was done for each of the 905 trail segments and 375 campsites.

Input Data. Trail network descriptions include route definitions and the mutual visibility lists. A route is defined as the series of trail segments and campsites which are connected sequentially (Schechter 1975). Individual segments or campsites may be common to several routes. The trip length in days must also be specified for each route.

User characteristics necessary for the simulator are total number of parties for the period to be simulated, party size distribution functions, and arrival patterns. These patterns are described for the number of parties that arrive during a week by days and by hours.

Once users arrive at the wilderness, they begin to interact with the trail system. Trailhead selection patterns, mode of travel patterns, and route selection patterns must all be specified. These patterns define different trailhead selection, mode of travel and route selection distributions. Transit time and camp departure time functions are also assigned.

OUTPUT FROM THE SIMULATOR

Output from the simulator comes in the form of tables and matrices which aggregate data on encounters and use levels. Replications on the simulator give average figures and appropriate statistical analyses. Scenarios of different management strategies allow the manager to compare the ramifications of the alternative actions.

Output Tables. Since numbers alone do not give a complete picture of the relationship between use and impact, some of the output tables categorize encounters and use levels by type and size of party, by trip length, or by location. Locations of encounters are further broken down as meeting or overtaking encounters on the trail or as encounters in camp. Other tables gather data on encounter and use levels by party, by trail segment or camp, and by day of the simulation. Encounter levels are used to assess the impact on the wilderness experience while use levels are used to assess resource and facility condition.

Scenarios. The manager has an opportunity to specify different management schemes called scenarios to be simulated. For example, it might be decided to close a trailhead or build a new trail. Before that is done, it would be helpful to know the effects of that decision on use throughout the area.

Typical scenarios would be ones in which total use is increased or decreased. The temporal distribution of use can be altered by changing the arrival patterns and distributions. The affects of trailhead quotas or travel zone limits on encounter levels and use levels could also be determined. Changes in spatial distribution of use offers one of the best ways to separate conflicting uses. Areas can be zoned for a particular use or trailheads and routes can be designated

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for specific users. Stock trails and large group campsites are examples of ways to alter spatial distribution.

Results from the scenario runs will often bring to light effects which could not have been predicted through conventional methods. Adverse levels of encounters or use could appear at new locations as a result of changing trailhead selection patterns. It must be remembered, however, that travel behavior is based on past use patterns and that some management actions might result in changed behavior. In these cases the best predictions of changed behavior should be used. The end result is a management program which distributes use without exceeding the optimum carrying capacities.

LITERATURE CITED

SCHECHTER, M. 1975. Simulation model of wilderness-area use. Resources for the Future, Washington, D.C. 172 p. + Appendix.

ANALYSIS OF RHYOLITE CANYON WATERSHED, CHIRICAHUA NATIONAL MONUMENT: A PROTOTYPE STUDY TO IMPROVE THE EFFICIENCY OF NATURAL RESOURCE DECISION MAKING[1]

Michael M. McCarthy[2], Anne F. Frondorf[2] and Lewis S. Albert[3]

INTRODUCTION

As man's impact continues, planners are increasingly called upon to collect information about natural resources that can be used by decision makers to predict the consequences of a given action or cumulative actions. Ideally, predictive models should be developed for a variety of regions and be applicable to a similar variety of scales and spatial configuration at any location. Such a system of models would include site and regional ecological processes and the relevant socioeconomic and sociopolitical and land allocation forces.

The goal of such a grouping of models would be a decision making system that enabled one to look at various conditional perturbations before implementing proposals and determine the consequences to natural resource processes. This demands a "baseline" study as a point from which conditional forecasts can be superimposed.

Such a baseline study must go beyond the basic resource inventory that is typically brought into the planning/decision making system. A methodology is required that defines not only detailed natural resource properties but *the interrelationship of those attributes into processes.*

In process-oriented approaches to planning and decision making, it is axiomatic that the objectives of a study must be clearly defined. To meet the "baseline" requirements of managers at Chiricahua National Monument, the following objectives were defined:

1. Development of an information system that assists in an understanding of the natural resource properties and processes within the Monument.

2. Development of an information system with the detail of species-specific information and the potential of thousands of bits of information.

3. Development of an information system with the capability to produce two and three dimensional computer graphics--from maps to perspective relationship illustrations.

4. Development of an information system with the capability to allow the resource manager to develop models of optimization and baseline assemblages of data.

5. Development of an information system that could serve as the foundation for future conditional simulation models.

6. Development of an information system that could be transferred to other parts of this monument as well as to other areas.

This paper documents an operational methodology that was developed to meet these objectives.

STUDY AREA

Chiricahua National Monument is located in Southeastern Arizona, approximately 100 miles east of Tucson. The Monument represents a total area of 10,645 acres. Several factors combine to make Chiricahua a unique area of study. The Monument is part of the basin and range topographic system which characterizes southeastern Arizona and exists as a mountain island surrounded by a sea of grass. This physical isolation, in conjunction with the proximity of Mexico with its tropical influences, serves to provide an area of diverse biological communities including several rare or unique species. This biological complexity is compounded by the physical complexity provided by the myriad of volcanic columns and the generally severe topography.

Within the Monument, a study watershed was chosen as a prototype for methodology development. Rhyolite Canyon watershed comprises 2,700 acres, includes most of the major visitor trails, and is representative of the entire Monument. This designation of a small area was purposefully done to allow for a very intensive data collection and examination of alternative methodologies.

METHODOLOGY

The methodology proposed is based on three basic premises:

1. A clear definition of the objectives that are to be met.

2. The selection of a prototype study area to test out various methodologies prior to any actual mapping of information in entirety.

3. A diligent effort to reduce cost requirements through reliance on such procedures as: variable intensity sampling, simultaneous and multiple cluster analysis, diagnosis of resource processes or systems, identification of indicator data and use of existing software packages.

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[1]Acknowledgment is given to William Rasmussen, Director of the Laboratory for Remote Sensing and Computer Mapping, for spatial information system software development and technical advice; Eric Roberts, School of Renewable Natural Resources, for support illustrations; Harry Goforth, Computer Center, for technical assistance with the cluster analysis program; Warren Steenbergh, Cooperative National Park Resources Study Unit, for initiating and administering the grant that resulted in this study; Hanna Cortner and David Thorud, School of Renewable Natural Resources, for providing additional financial support; and John Thames, School of Renewable Natural Resources, as co-investigator of this project.

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[3]Chiricahua National Monument, Wilcox, Arizona.

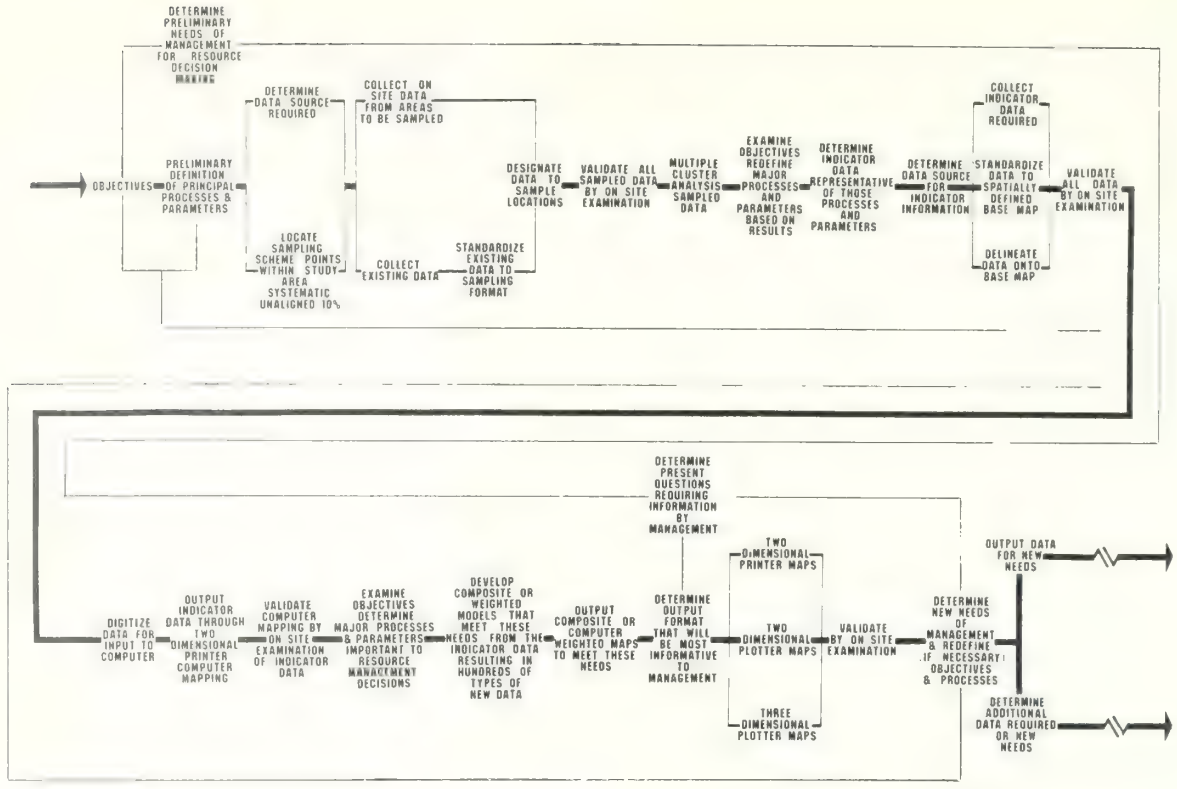
DETERMINE PRELIMINARY NEEDS OF MANAGEMENT FOR RESOURCE DECISION MAKING
OBJECTIVES
PRELIMINARY DEFINITION OF PRINCIPAL PROCESSES & PARAMETERS
DETERMINE DATA SOURCE REQUIRED
LOCATE SAMPLING SCHEME POINTS WITHIN STUDY AREA SYSTEMATIC UNALIGNED 10%
COLLECT ON SITE DATA FROM AREAS TO BE SAMPLED
COLLECT EXISTING DATA
STANDARDIZE EXISTING DATA TO SAMPLING FORMAT
DESIGNATE DATA TO SAMPLE LOCATIONS
VALIDATE ALL SAMPLED DATA BY ON SITE EXAMINATION
MULTIPLE CLUSTER ANALYSIS SAMPLED DATA
EXAMINE OBJECTIVES REDEFINE MAJOR PROCESSES AND PARAMETERS BASED ON RESULTS
DETERMINE INDICATOR DATA REPRESENTATIVE OF THOSE PROCESSES AND PARAMETERS
DETERMINE DATA SOURCE FOR INDICATOR INFORMATION
COLLECT INDICATOR DATA REQUIRED
STANDARDIZE DATA TO SPATIALLY DEFINED BASE MAP
DELINEATE DATA ONTO BASE MAP
VALIDATE ALL DATA BY ON SITE EXAMINATION
DETERMINE PRESENT QUESTIONS REQUIRING INFORMATION BY MANAGEMENT
DIGITIZE DATA FOR INPUT TO COMPUTER
OUTPUT INDICATOR DATA THROUGH TWO DIMENSIONAL PRINTER COMPUTER MAPPING
VALIDATE COMPUTER MAPPING BY ON SITE EXAMINATION OF INDICATOR DATA
EXAMINE OBJECTIVES DETERMINE MAJOR PROCESSES & PARAMETERS IMPORTANT TO RESOURCE MANAGEMENT DECISIONS
DEVELOP COMPOSITE OR WEIGHTED MODELS THAT MEET THESE NEEDS FROM THE INDICATOR DATA RESULTING IN HUNDREDS OF TYPES OF NEW DATA
OUTPUT COMPOSITE OR COMPUTER WEIGHTED MAPS TO MEET THESE NEEDS
DETERMINE OUTPUT FORMAT THAT WILL BE MOST INFORMATIVE TO MANAGEMENT
TWO DIMENSIONAL PRINTER MAPS
TWO DIMENSIONAL PLOTTER MAPS
THREE DIMENSIONAL PLOTTER MAPS
VALIDATE BY ON SITE EXAMINATION
DETERMINE NEW NEEDS OF MANAGEMENT & REDEFINE IF NECESSARY OBJECTIVES & PROCESSES
OUTPUT DATA FOR NEW NEEDS
DETERMINE ADDITIONAL DATA REQUIRED OR NEW NEEDS

FIGURE 1.

The complete methodology developed is illustrated in Figure 1. For ease in understanding, the succeeding written description has simplified the methodology into eight steps. Due to restriction on the length of this article, Figure 1 should be examined closely as the diagram contains details not included in the following discussion:

1. Definition of Principal Processes and Parameters/Determination of Data Sources Required. A preliminary listing of natural resource properties: land, air, water, floral, and faunal systems, was used in the preparation of a data-availability-matrix, which provided a concise display of the existing data which could be utilized in the study. The "negative" of the data-availability-matrix displayed those data types which were not already available and served as the basis for decisions as to which data types would be assembled during the on-the-site collection efforts.

2. Sampling Scheme/Location/Data Standardization. A ten percent, systematic unaligned sample was applied to the prototype watershed (Berry 1962; Cockran 1953; Holmes 1967; Keyes et al. 1973; Quenouille 1949). Figure 2 illustrates the location of the sample units within the study area (each unit equalled one square hectare). The total of data types, from existing sources and field collections, was standardized into a numerical system, which could be easily entered into a computer for use in a cluster analyses program. In such standardization, ranges of levels within each data type are assigned a representative integer. It is these integers which are then entered in the computer.

3. Multiple Cluster Analyses on Sampled Data. A series of "multiple cluster" analyses was performed using the clustering program, CLUSTAN (Wishart 1969). Each cluster analysis involved different numbers of sample units. The rationale behind such a "multiple cluster" approach was to insure the validity of the relationships revealed in the dendrograms. If after altering combinations of parameters and individuals the same essential functional relationships were displayed in all of the resultant dendrograms, the interrelationships were assumed to be valid. The decision to run the assembled sample point data through cluster analyses before inputting data for the entire study area was based on two premises:

a) In several previous information system studies, total costs and man-hours had been prohibitively high. A reason for this was that many different data types had to be assembled and maintained as files within the computer for use in map production often without any understanding of the real need for the data collected. Cluster analysis permits a selective reduction of the amount of data which must be eventually inputted, while maintaining the capability of initially analyzing many more data types. If the clustering results show that six different data types are always found in conjunction with one another, only one of the six need be explicitly carried along with it. Thus, cost/time efficiency, in terms of data in-put procedures, would be increased.

b) The output of a cluster analysis program, the dendrogram, is a display of the

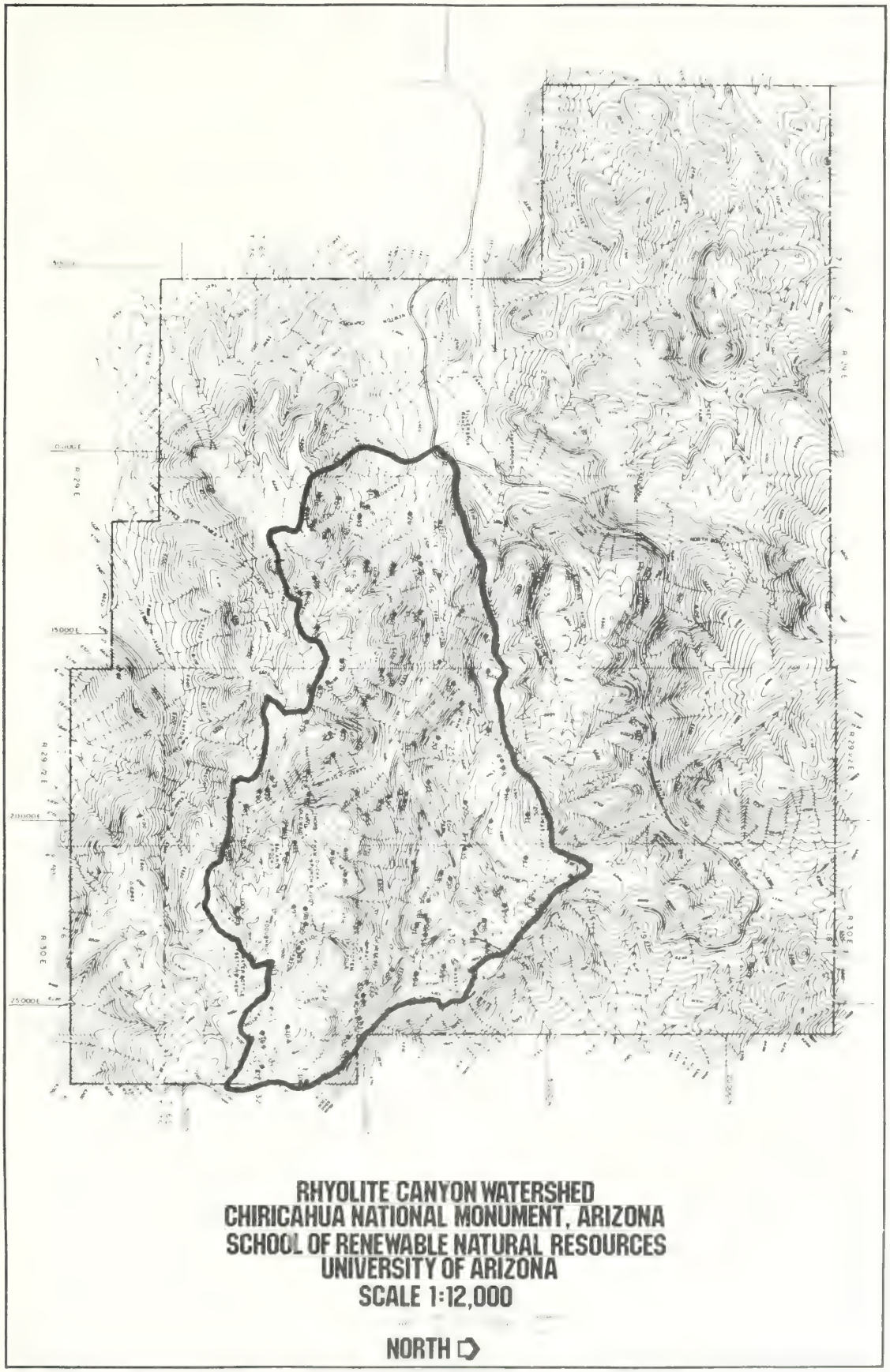
RHYOLITE CANYON WATERSHED
CHIRICAHUA NATIONAL MONUMENT, ARIZONA
SCHOOL OF RENEWABLE NATURAL RESOURCES
UNIVERSITY OF ARIZONA
SCALE 1:12,000
NORTH

FIGURE 2.

functional groupings or interrelationships of the natural resource attributes measured and provides insight into the system being examined.

At the end of this multiple cluster procedure, it was noted that all the dendrograms were illustrating similar patterns of groupings. Although cluster analysis procedures allow understanding of many levels, it appeared in this study that nine major functional "groups" of resource processes comprised the major resource base of the study area.

4. Redefine Major Processes/Interrelationships Based on Cluster Analysis Results. For each of the nine groups, hundreds of individual data bits were represented. An analysis of this data allowed the creation of "model" or "representative" descriptions of the nine systems in terms of dominant interrelationships of: species of wildlife, species of vegetation, and land, air and water characteristics. These descriptions of operative resource processes were then delineated into major dominants through illustrations to assist the decision makers/managers.

Figure 3 depicts one of the dendrograms from the many cluster analysis procedures performed and illustrates the nine groupings identified along the horizontal axis of that plot. Figures 3, 4 and 5 are graphic representation of the nine systems of resource groups identified by the sampling and statistical analyses. Each depiction notes only the major characteristics of a group while extensive data lists actually characterize the interrelationship in greater detail.

5. Determine Indicator Data Representative of Processes. With the cluster analyses completed, the actual formation of the data base began with the selection of the indicator resource parameters which would be inputted into the computer and formed as permanent data files. These files could then be used in the production of base maps of weighted, composite maps through the computer. As has been discussed above, the cluster procedure reveals linkages between parameters and allows for the reduction of the number of parameters which must be inputted. As this characterization of the groups proceeded, it became apparent that cer-

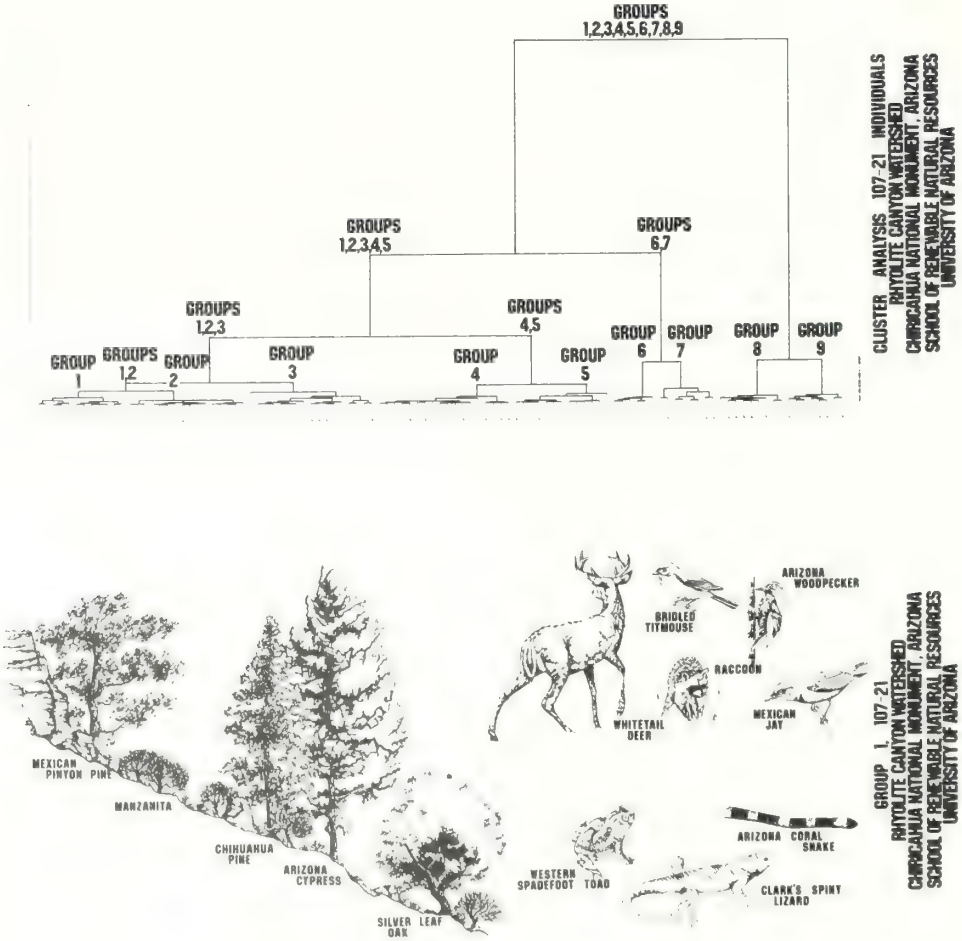

FIGURE 3.

FIGURE 4.

tain resource parameters were more important than others in determining the functional relationships within the study area. For example, in all of the cluster analysis results, elevation, slope, vegetation type, and vegetation density appeared to be indicator parameters for this prototype area. It was decided to form files for only those indicator parameters. Since certain data (e.g., slope, orientation, etc.) can be obtained from the computer through separate programs, only a small number of data need actually be mapped and entered into the computer.

6. Standardize Data and Input to Spatial Information System. The indicator parameters were entered for the entire study area by digitizing the information off of prepared base maps. For example: Elevation was digitized directly from the United States Geological Survey contour maps. Vegetation density was transferred from a previously existing vegetation map of the Monument (which had first been verified with the air photos) to the base map.

7. Develop Composite or Weighted Models. The value of the approach is clearly demonstrated when, after entering a small number of parameters into the computer, the decision maker has the capability to manipulate and display over a thousand separate types of data, down to the individual species level. This capability to manipulate original data into many other data types is illustrated in Figure 6. These data types are either obtained directly by the combination and weighting of the original parameters or indirectly by the combination and weighting of second-, third-, or fourth-level data types. The last column of Figure 6 is representational as space requirements preclude identification of all the detailed data now contained within the information system.

8. Output Computer Graphics in Format Most Useful. After the data files are assembled, any information can be retrieved depending on the needs of the manager/decision maker. Existing computer graphic techniques (Durfee 1974); Laboratory for Computer Graphics and Spatial Analysis 1975) enable one to project information required in a variety of formats: two dimensional printer maps, two dimension plotter maps, and three dimensional relationship illustrations. Examples of this capability are illustrated in Figures 7, 8 and 9. Figure 7 depicts such indicator data as: elevation, drainage, patterns and vegetation density. Figure 8 shows location of the areas occupied by group eight of the nine groups identified by the previously discussed cluster analysis. Figure 9 depicts the location of Apache fox squirrel, a species unique within the U. S. to the Chiricahua Mountains. While these are only a few examples, through the weighting and compositing of data, a number of types of natural resource information can be produced.

SUMMARY

At the present time, this system is operational and is responding to actual managerial requests for information before management/planning decisions are implemented. The actual cost for the system was approximately $10,000. This figure does not include overhead but does represent all personnel and computer time to create a very intensive understanding of "baseline" natural resource conditions. Other areas differing in size or resource complexity may affect this cost figure but it is reasonably accurate.

The system should not be thought of as replacing the park manager, his staff or basic research activities. The methodology simply holds information and aids decision-making in a practical, day-to-day manner as they attempt to conserve and manage the resources of the park. Indeed, for

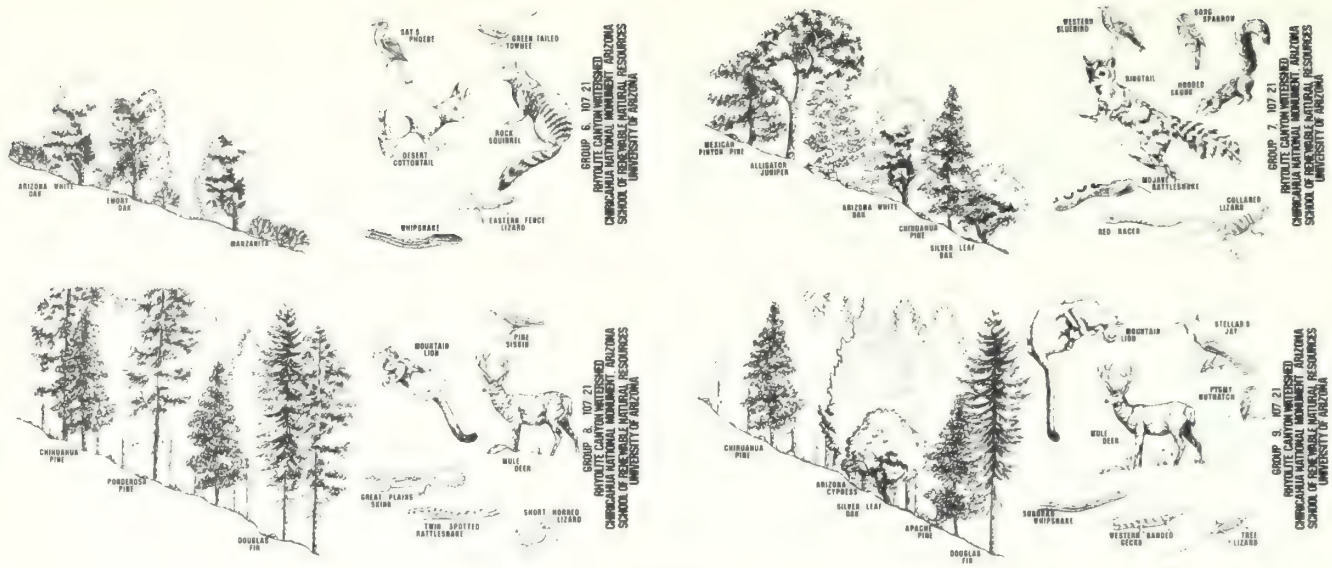

FIGURE 5.

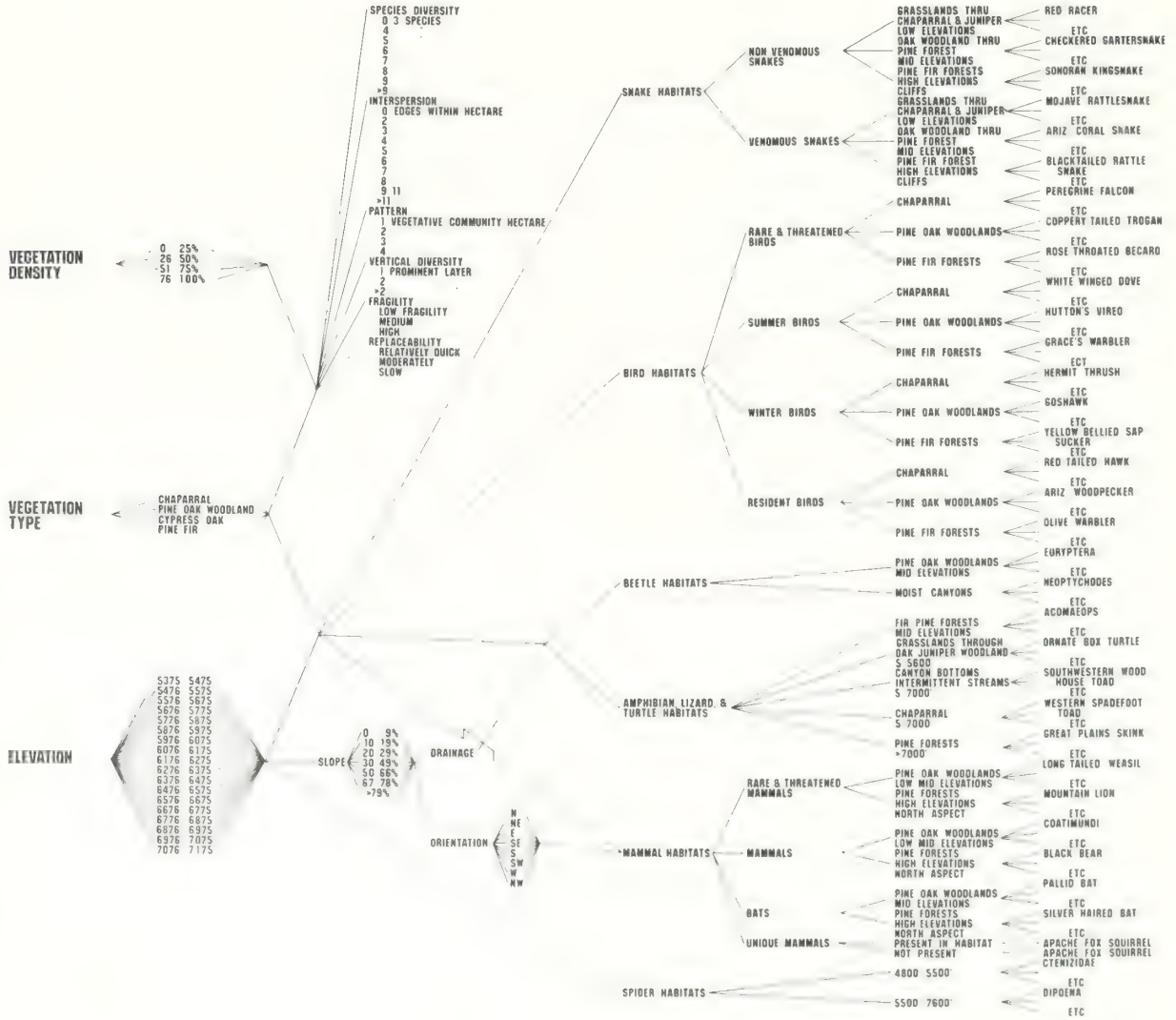

FIGURE 6.

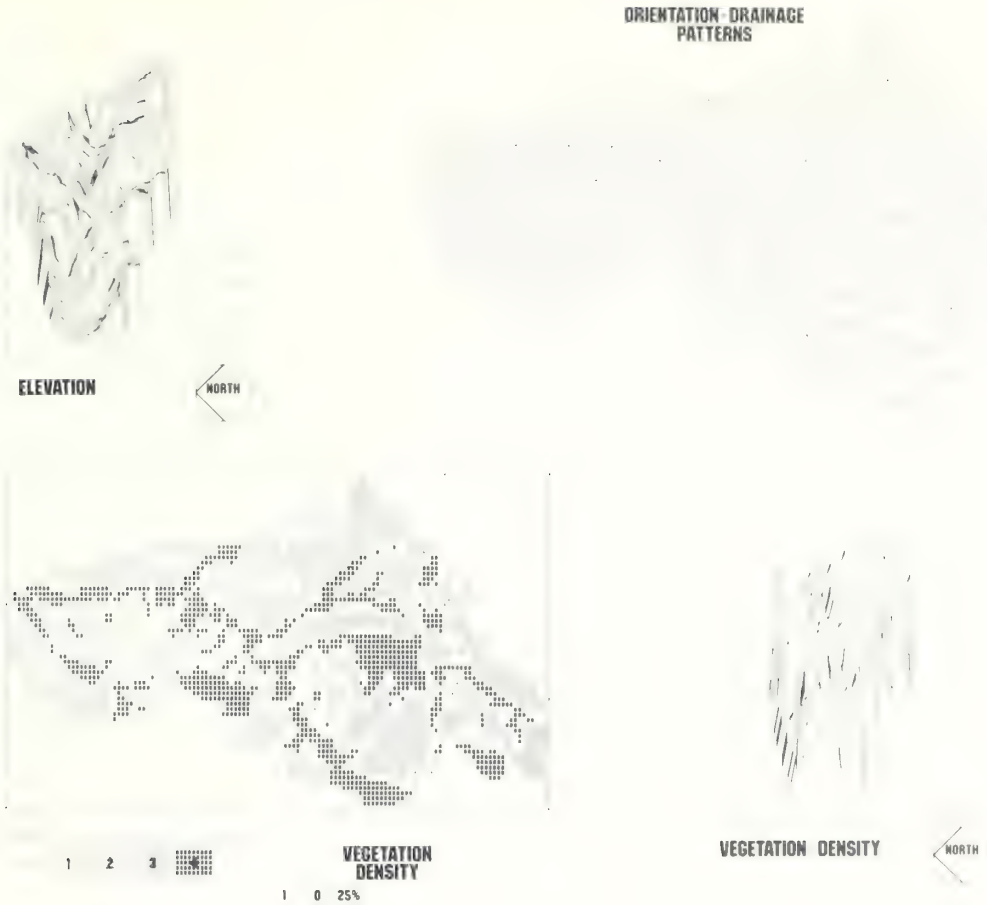

FIGURE 7.

FIGURE 8.

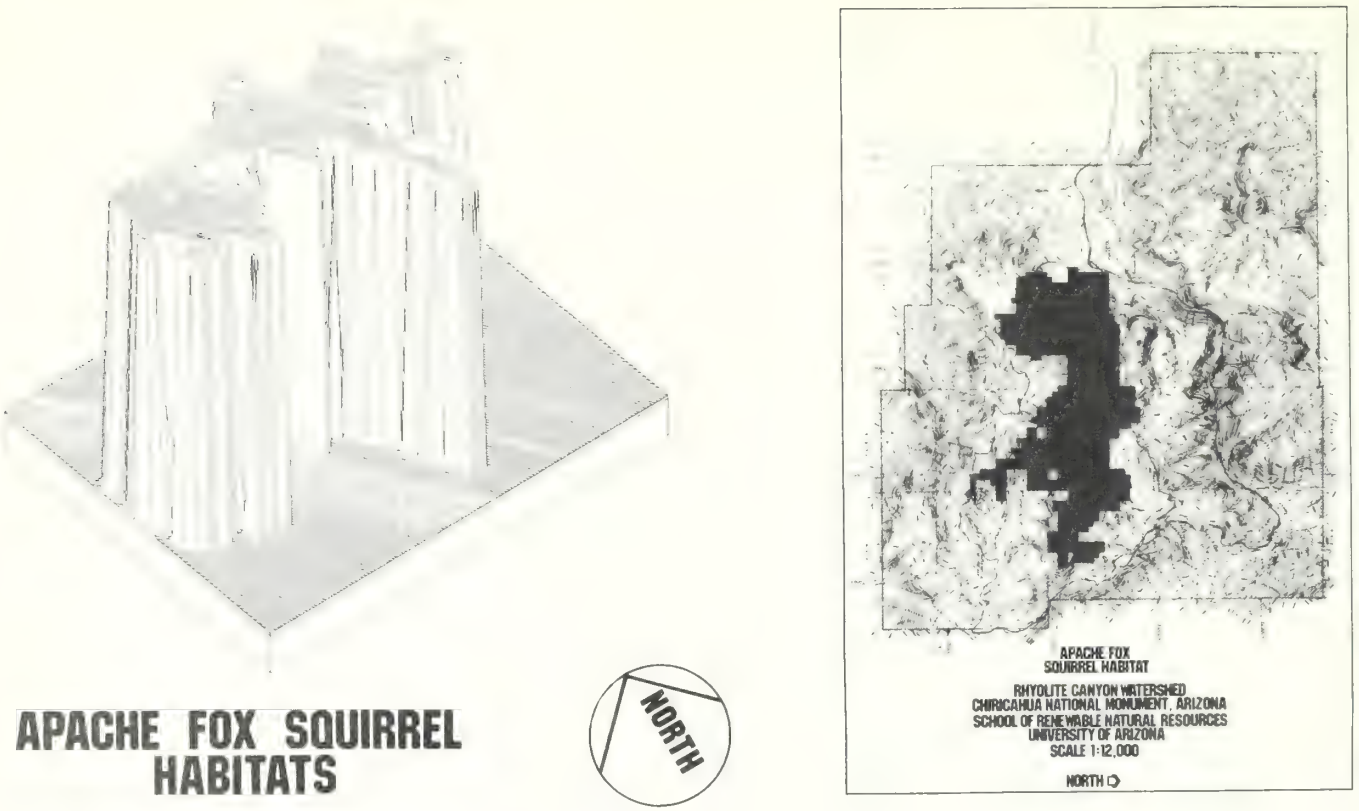

FIGURE 9.

the system to remain vital and up-to-date, it requires periodic feedback from the Park personnel as to any major natural or man-made alterations to the resource base.

In the near future, this methodology will be applied to the entire Monument. This expansion would be concluded by the production of a working manual which the Park personnel can use to answer many of their questions themselves, leaving only the more complex problems to be dealt with the assistance of the computer.

With a workable data base of resource processes established for the entire Monument, the next phase would involve the evolution of a series of simulation models.

REFERENCES

BERRY, B. J. L. 1962. Sampling, Coding and Storing Flood Plain Data. Agricultural Handbook No. 237, U. S. Department of Agriculture.

COCKRAN, W. G. 1953. Sampling Techniques. John Wiley and Sons, Inc., New York.

DURFEE, R. C. 1974. ORRMIS - Oak Ridge Regional Modeling Information System - Part 1. ORNL-NSF-EP-73, Oak Ridge National Laboratory.

HOLMES, J. 1967. Problems in Locational Sampling. Ann. Assoc. Amer. Geog. 57:757-780.

KEYES, D. L. and V. BASOGLU. 1973. Comparative Analysis of Sampling Designs for Geographical Data. Department of Landscape Architecture, University of Wisconsin.

LABORATORY FOR COMPUTER GRAPHICS AND SPATIAL ANALYSIS. 1975. SYMAP. Graduate School of Design, Harvard University.

MORRISON, J. L. 1970. A link between cartographic theory and mapping practice: the nearest neighbor statistic. Geog. Rev. 55:494-510.

QUENOUILLE, M. H. 1949. Problems in plane sampling. Ann. Math. Stat. 20:355-375.

WISHART, D. 1969. CLUSTAN IA. Computing Laboratory, University of St. Andrews.

MULTISPECTRAL SCANNER DATA: USEFUL FOR PLANNING AND MANAGING THE NATIONAL PARK SYSTEM?

Harvey Fleet, Kenneth Muth, and Nancy Fries[1]

The environmental impact statement, mechanized systems for managing and analyzing information, the requirements of numerous statutes and regulations, and the use of remote sensing for gathering environmental information are some of the more conspicuous elements of land-use planning in this decade. I believe the abundance of papers on these topics during this conference amply illustrates the effect of these influences upon National Park Service activities. In particular, a number of investigators utilizing and studying methods of remote sensing for gathering information have reported here on their findings. I would like to add to this record an account of our own experiences and observations in this field.

The objective of our study was two-fold: to produce a vegetation map of the Congaree Swamp in South Carolina and to acquaint ourselves with the technique of multispectral analysis. The vegetation map was to have served as a principal source of information for constructing and assessing boundary and management alternatives for the Congaree Swamp New Area Study.

The Congaree Swamp, an area of some 25,000 acres approximately 20 miles southeast of Columbia, South Carolina, is an alluvial floodplain containing the last significant tract of virgin southern bottomland hardwoods in the southeastern United States. The uncut portion of the area may be the last major remnant of a mature bottomland hardwood ecosystem that was once common along major watercourses through the Southeast. No other such extensive floodplain forest that approaches this area in maturity and size of trees has been located either in South Carolina or the Southeast. The vegetation is quite complex, one investigator reporting at least 11 community types (Gaddy et al. 1975).

Common tree species--out of a total of about 40--are loblolly pine, sweet gum, swamp chestnut oak, laurel oak, overcup oak, ironwood, white ash, water tupelo, swamp tupelo, and bald cypress.

To produce the vegetation map, reflected light energy in four wavelength bands--500-600 mu (millimicrons), 600-700 mu, 700-800 mu, and 800-1100 mu--was collected at midmorning on May 5th (of this year) by a multispectral scanner aboard a NASA aircraft flying at 10,000 feet. This energy was recorded from squares about 25 feet on a side, the minimum resolution of the data. Concurrently, training fields of approximately 250 feet on a side were selected and sampled for tree species composition and percent cover. (Thus, for example, several stands of water tupelo/bald cypress were located and sampled for percent cover in several canopy classes; 80 percent water tupelo, 20 percent bald cypress as cover-dominants; 50 percent water tupelo, 20 percent bald cypress and 20 percent other species as cover-subdominants, and so on.) In all, some 21 training fields were used in the analysis.

The multispectral data were processed at NASA's Earth Resources Laboratory in Slidell, Louisiana, where it was possible, by ratioing the energy in channel 4 to that in channel 2 for each resolution cell, to produce a display of the data. This display allowed direct viewing, location and examination of training fields, and calculation of means and accompanying standard deviations in each of the 4 channels for all the resolution cells in a given training field. Histograms of reflectivity vs. frequency could also be directly observed, allowing rejection of training fields whose frequency distributions were highly multimodal.

Each of the data set's resolution cells were then classified into one of 13 categories by comparing each cell's 4 energy values (one datum for each of the 4 wavelength bands) with those of the training fields.

Rather than discussing the specific contents of the map, which are of more narrow interest here today than the broader question of multispectral analysis and its utility to NPS planning and management--the subject of my talk--I should like to spend the time remaining citing our general impressions of the potential merits and problems of this technique.

To date, multispectral analysis appears to have capability for:

1. Rapid mapping of areas. The vegation map of the Congaree Swamp, an area of some 25,000 acres, took 3 weeks to produce, the actual collection of data (excluding 3 days for ground-truthing) only a matter of hours. Because the data are collected and processed by machine, even areas considerably larger than the Congaree--a million acres or more--might possibly be mapped in a similar length of time (assuming, however, the prior establishment and sampling of training fields and the perfected performance of the processing software). The availability of current and future satellite data for almost all National Park Service areas negates any problems of data acquisition.

2. Periodic updating of maps. The routine, periodic acquisition of data by satellite makes possible the continual updating of maps. The potential benefits of such recurring surveillance to resource management are vast. The onset and progress of insect or disease infestations, changes in water quality, or even possibly conditions of fire susceptibility could be readily observed.

3. High accuracy and objectivity. Because the data for an entire area are collected and processed by machines that are quite indifferent to the data's contents, the potential for high accuracy and absolute objectivity exists. Bias can, of course, be introduced during the analysis, but the original data set remains free of any prejudicial preconceptions.

4. Partitioning of data categories. The classifying of each resolution cell by the computer allows all cells of similar classification to be displayed independently of other cells. Thus, for example, in the Congaree the location of water tupelo/bald cypress communities could easily be isolated and printed separately from the ten other categories of vegetation. The same technique also permits precise acreage computations, very difficult or even impossible by planimetric methods.

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5. Low project-by-project cost. Because the satellite data tapes are available at relatively low cost (presently $200 per frame of 100 nautical miles on a side), the mapping and remapping of areas may be accomplished very cheaply, assuming the amortization of the initial equipment purchase and the inclusion of day-to-day operating expenses.

In addition to these potential merits we have discovered certain limitation that include:

a. Location of training fields. Training fields must be precisely located on the image produced by the numerical data. So that categories can be correctly and meaningfully identified on the output product, the training fields should accurately define what is actually present on the ground and must be precisely located on the image. We were plagued with this problem in the Congaree, primarily because of a lack of geographic reference points.

The swamp is an almost perfectly flat landscape with virtually no distinguishing geographic features--a uniform, extensive, apparently unvarying forest canopy). We have discussed several possible remedies, including radio beacons and reflectors. In areas with more easily discernible landmarks and larger training fields (as required for satellite data) this problem may not exist.

b. High initial cost. Routing processing of multispectral data requires an image display device, a computer, and an output recording device. Current costs for these items, respectively, are $40,000, $100,000-150,000, and $80,000-150,000. Depending on the purchase of a computer and the complexity and capability of the output recording machine, the system could cost between $120,000 and $340,000.

c. Inadequately developed statistical procedures for classifying the data. The development of methods for analyzing multispectral data is still in its infancy, and in cases where spectral signatures from various training fields are quite closely related--as they were for several of the mixed hardwood communities in the Congaree--the classification of resolution cells into one category or another becomes quite difficult. In addition, the calculation of probabilities of misclassifying the cells and the determination of rational divergence thresholds are largely uncharted territories.

Although we have learned much from our work in the Congaree, we were unable to answer several important questions:

I. Will the products generated from Landsat-II data be useful to management and our planning and design process? The resolution of the next generation of Landsat satellites--to be operational around the end of this decade--will be 30 meters. We wonder if this will be suitable for general management planning, development planning, comprehensive design, and resource management. (The resolution of the Congaree map is about 8 meters and as such not directly useful for answering these questions).

II. Can multispectral data produce meaningful maps in areas of high topographic relief, varying slope aspects, or extensive exposures or bare soil, rock, ice, or snow? The Congaree contains none of these features, which manifest themselves most prominently in our Western and Alaskan parks.

III. Will the separation of spectral signatures and the classification of resolution cells be easier in areas where the vegetation is less complex than in the Congaree. We have reason to believe that the separation of the many subtly different hardwood communities was not fully satisfactorily performed. Many Western and Alaskan parks have only three our four principal vegetative communities, in contrast to the Congaree, which contains many more--the precise number depending on your phytosociological viewpoint. We suspect that classification of fewer categories would not involve some of the difficulties we encountered in the Congaree.

IV. Will the location and sampling of the larger training fields needed for the satellite data present any problems? In the Congaree the training fields were roughly 250 feet on a side; for the satellite data, they must be about a quarter mile on a side. At this point we do not know who will carry out the sampling, how it will be accomplished, and whether location of the training fields will be a problem.

We assume that other investigators proceeding with the use of multispectral analysis are shedding light on these questions. We would hope that most, if not all of them would be answered with some certainty before the Service would commit itself to any large-scale, expensive program involving the use of multispectral data.

LITERATURE CITED

GADDY, L. L., THOMAS S. KOHLSAAT, EUGENE A. LAURENT, AND KENNETH B. STANSELL. 1975. A vegetation analysis of preserve alternatives involving the Beidler Tract of Congaree Swamp. Unpublished report. Division of Natural Area Acquisition and Resources Planning, South Carolina Wildlife and Marine Resources Department.

COMPUTER-AIDED PARKLAND RESEARCH OPTIMIZATION

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JUSTIFICATIONS FOR AN OPTIMAL SYSTEM

Managers of wild parklands need information to improve their decisions. Citizens seek knowledge, for in their enlightenment about parklands they experience pleasures, reduced risks, and increased surety of their heritage. Park administrators need knowledge, for with knowledge they can increase benefits (particularly noteworthy ones), decrease risks and costs, and assure the efficiencies of reasonable stability. There are many reasons why parkland research is needed. Even though a need may be felt, there may not be sufficient justification for doing research to meet that need. *Justification* is the kernel of the modern research question; it has not always been so.

What research is to be done is a question that begs the more fundamental one of how do we know research should be done. There are several major ways of deciding: *Authority,* (i.e., some expert said it was necessary); *Induction,* (i.e., we studied systems, researched and unresearched, and observed significant desirable differences in the research areas); *Correspondence,* (i.e., we deductively resolved that well-known principles applied to specific areas produce expected results). Currently, it appears that the most important decision base is that of *Pragmatism.* The dominant justification is a positive answer to: Will it work, or will utility increase? All of these bases have merits. They may advantageously be focused on particular research proposals. Justification for a proposed project can be expressed as a belief statement ranging from 1.0 as certainty to 0 as completely unjustified. It is important, we think, to recognize that *to know* that research *must* be done is a belief statement. That belief is subject to an individual's criteriology which is a function of the decision maker's culture and recent sociology. To *know* is a complex and personal calculus. It is typically (but erroneously) called a "subjective" decision, but it can be analyzed and quantified, given enough time and study. Therefore, it is or can be made objective. This paper is an effort toward analyzing this process, making it more precise, providing computer aids to the complex process, and articulating processes clearly so that enhancing feedback can be applied.

Implicit in doing a particular research project is the premise: to do this research is good. There is manifest in every active research project a prior judgment of goodness; there exists some axiological base (Weinberg 1970). For future research proposals, there may be required the articulation of this value system for research as fundamental to an enlightened parkland research system.

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There have been many papers presented at these meetings on parkland research. It is obvious that parkland research is a state-federal-private amalgam, variable, independent, and spawned by problematic storm clouds. A "collection of accidents" (Nichols 1971:30), it does not exist as a system; any resemblance is coincidental.

Parkland research was once enshrined as *basic* with the accouterments of pure science, of purposeless meanders, of pursuits of whims, of tales of quaint discovery. Those days are over. Like a species that is endangered, not because of mutation but because of habitat change, research is not what it used to be. Wishing for the old days (which were just a few days ago) will not make them appear. To follow an idea, "any idea," to study "just because" may not be possible again. To face this condition is reasonable--not pleasant --but reasonable.

The reasons are many but the major ones are that:

(1) There are more resource users and less resources of all types per capita.

(2) There are increasing conflicts among people, particularly groups, for these resources. These conflicts are better articulated and more conspicuous to the decision maker than ever before. His decisions, likewise, are more conspicuous.

(3) There are more scientists than ever before competing for limited resources. Whatever these limits, the proportions are likely to be smaller. Opportunity space or resources are limited.

(4) There is competitive bidding for limited research funds. Priorities are rarely debated between quaint whims of basic scientist A and B.

(5) There are stringent demands on limited research budgets. These are not likely to increase substantially. Weinberg (1970:612) said, "The dwindling of the scientific budget has put great pressure on scientific administrators at every level to make sharper, and often more painful, choices."

(6) The real value of money presently tends to decline.

(7) Costs to obtain the same former goods and services increase. Answers to modern questions often require costly equipment.

(8) Larger organizational structures require more administrative costs. These overheads typically become fixed personnel costs. The increased efficiency per person added is not linear. Coordination problems increase with staff additions and often negate expected gains.

(9) The mean cost per conclusion increases;

the cream has previously been skimmed.

(10) Research funding has a sigmoid growth rate and has or will shortly reach the inflection point. Results will be expected to continue to be produced at past rates, and when they do not further dissatisfactions with scientific output will emerge.

(11) There is an acute sense of urgency about many topics, encouraging adoption of a simultaneous research strategy, typically more costly than a sequential strategy (Ackoff 1962).

(12) Many decisions are now precipitous. There are cases of black or white. Formerly a poor decision could be "worked over" or corrected. Increasingly the decision maker needs information in order to be right the first time.

(13) Broad national interests are often at stake, either in demonstrating success, protecting a national resource, or preventing a political problem.

Most researchers operate in a state of mild panic, hopeful that crises will not emerge before they complete their studies, hopeful they can provide full or partial answers to those that do arise, hopeful the problem will not disappear before the project does, and hopeful they can sort through their knowledge to fit a poorly hewn answer to a blunt question. Simon (1973:1) said that "to lay claims to the resources of his society, a scientist must produce what the society wants. And what it wants is a little knowledge and a lot of relevance." We do not defend this condition; we only recognize that it exists. To obtain financial support for science, its justification must be its ultimate usefulness.

As never before, the research community, particularly the parkland research community, must solve problems of research justification, largely in terms of utility, costs, and attention to real constraints. The question of how to optimize allocation of research funds is now important and is likely to increase in importance.

CONTEXT

There are five dimensions which define the context of the parkland research system. First, the context within which a viable research system may operate is one in which it competes fairly and on equal grounds with other research agencies. Some become faint-hearted at such prepositions fearing undersupport. We believe parkland will lose the early battles, but no worse than at present, and that more general competition for research funds can improve the tone, stamina, and success of a new research effort. Imbalances may be struck down and funds may be freed and available competitively for parkland research.

Another dimension of a viable research context is that in times of economic and other crises, research, like a personal savings account, should be the last thing to be discarded. This statement, easily acceptable to scientists, must be answerable to "Why?" and the answers are likely once again to lie in ultimate utility, in the social account, in the projected benefits, and various measures of the international welfare.

The third dimension is the awareness that the scientific research fund allocation process is not likely to appear rational. There are complex social, political, and ethical considerations involved that are said by some to be extra-scientific. The influences are dynamic (David 1973:21). We think that rosy expectations for rational behavior are unjustified, but we think that significant increases can be made in describing what is going on, assisting in making the decision process more efficient, and pointing out weaknesses needing corrective feedback. Science can "only do so much" in such situations, but we think a little would help a lot.

The fourth dimension, one absolutely essential for a viable research effort, is the allocator's realization of (1) the miniscule working force of scientists (in contrast to the number of managers, technologists, inventory specialists, accountants, and administrators); and (2) the miniscule research funds that actually go into parkland research (in contrast to livestock, forestry, or water research).

RESEARCH PREMISES

Research is action performed to gain inputs to decisions. These inputs, while used to make explanations, find their ultimate use in prediction. There may be research on objectives and how they are stated and weighted, on processes and their improvement, and on systems performance (feedback), but all are directed toward mastering the control of a system to serve men. The primary difference we see in basic and applied research is the time element--the longer the time lag before the conclusion from a research project is applied, the more basic is the study.

Seen from this perspective, parkland research is research oriented primarily toward mastery of the parkland system--an ability to control if necessary, but at least to predict accurately its future structure, dynamics, and relations and, simultaneously, its utility to actual and potential users. Thus we see the need for a *research system*, not merely research. Embodied in the concept of a parkland research system are major transitions. The requirements are massive for they include doing good science while catching up, getting ahead, and preparing for the scientific milieu of the coming society. A major trap in shaping such a research system is that the system may become a means for deciding about, not the future, but the present.

To avoid this trap several strategic decisions must be made.

The interests of individual investigators must be aligned with the plan. Personal "pet" projects must be deferred, written about and promoted elsewhere, or conducted during nonagency periods. No creative worker can handle or solve all of the questions or ideas he produces. Most researchers have a wide variety of interests at any time; they vary generally, as evidenced by project changes. Teamwork toward long-term ends is likely to provide greater (or at least equivalent) satisfactions than those formerly available to scientists.

(1) Research on parklands must be directed toward real or potential choices. A choice has an anticipated future (Burgers 1975:195). Research must consciously involve decisions. Before work is done, the end must be faced: If you had an answer (any answer) to the question you raise, what would you do with it?

(2) Research in a parklands research system must be directed toward physical park

preservation and maintenance, or user experience enhancement. Other research on parklands for the greater social good (e.g., base data or normalcy) may be done, of course, but should be funded by and conceived as a part of the responsibility of research systems other than those identified as parkland systems.

(3) Research leadership, a desirable general goal, must come through innovative thought and approaches to the above criteria, the operation of a highly effective system, superior agency cooperation, and appropriate distribution of results to the intended or potential users.

(4) Research must be planned and the plans followed.

(5) Because of the time constraints and urgency that we perceive for such a research system, a hypothesis about usefulness of research results in some indeterminable future is untenable. We accept the need for the mutant idea that provides system diversity and long-term stability. We see little evidence of such events in parkland research in the past and suspect few in the future. Therefore we suggest that such funds be allocated only to special investigators. These funds should be about 5 to 10 percent of the research budget and at least a few percent of them should be allocated by lottery (Abert 1972).

(6) The scientific method, largely inductive, must be infused with deductive methods if a parkland research system is to have utility. Computer models, scenarios, and synthetic guidance systems must be developed. The simulation mode and consequence tables must become a part of research planning, experimental data analyses, and use of results.

(7) There is no way, in real time, to unlock the mysteries of 80 species, over 4 seasons, over 10 years, in 20 ecosystems, influenced by 10 levels of human use, and 15 major environmental variables. To solve one such problem at a rate of one factor per hour requires 10,965 years. The problems of parklands are more numerous than the above, the time required much longer. The answers to parkland problems must come from sweeping induction based on searches for isomorphic structures and careful studies of system *processes*. Predictive equations especially about energy flows and nutrient cycles as influenced by *types* of changes are needed. Even these are prohibitively numerous and lengthy. Therefore, large parkland system models are needed, primarily to determine the sensitivity of the system to various factors. These sensitivity analyses should then become the rationale for planned research. There are no further excuses for jumping from vague notions into mass programs. Delayed costs resulting from such analyses will be offset by the economies.

(8) A parkland research system will not provide answers to all parkland managerial questions. Those in the system must

(a) learn and make available present knowledge,

(b) know what research is being performed elsewhere and when it will become available to the parkland research system,

(c) get needed research done by extra-system personnel and agencies, and

(d) operate a research team to acquire the remainder of the needs.

(9) Those things which can be *discovered* must be assiduously separated from those things which must be *decided*. Experimentation is not an appropriate answer to all questions. Questions about goals and objectives are only answerable by decisions. While research may discover means for better articulating these objectives, they remain to be decided--a very human task. The separation is essential for focusing research performance, avoiding insolvable problems, evading inappropriate controversy which has hazards of diminishing support for the research system, and preventing overinflated expectations from the research system.

(10) The world shrinks. International answers to parkland problems are needed. Research questions can usually be phrased so they may have, if answered, multinational utility.

(11) More money will not always solve problems. As in ecosystems, certain stages of development in research systems must be passed before survival and growth can occur. Funds must be sought only for planned projects; additional funds can be sequentially diverted to projects which contribute to later solutions.

(12) Ideas do not come on command. Funds and manpower do not always produce answers. Ideas and breakthroughs appear to involve stochastic responses; they appear in ways not wholly susceptible to management (Hackerman 1975). Total research system management need not be the quest; major improvement is a reasonable alternative.

CRITERIA FOR AN EFFECTIVE PARKLAND RESEARCH SYSTEM

A parkland research system is not the sum of the state or regional systems. A system is defined by a set of criteria. A system is known to exist when it meets the following:

1. It has a well-articulated set of research goals and objectives. These must be written, measurable, and dynamically changing to reflect the best current thinking and be free of specified methodology.

Renewed effort must be made to provide measurable objectives, for in the achievement of specific objectives parkland utility increases. Objectives must express intangibles as well as tangibles and efforts made to make them more measurable or to change the performance measures.

Clearly it is not possible for a parkland research system to do all types of research. The objectives should clarify how selection and/or rejection should be made.

2. The system must be institutionalized. Long-term studies, and stability of support are dependent upon such an institution (Gershinowitz 1972:381). Perhaps a lead agency may emerge.

Otherwise centers, agency branches, or a federated agency may be useful.

3. There must be some minimal level of unfaltering support. Programs may wax and wane but without stability, personnel changes are likely, project progress broken, enthusiasm may decline and coordination and cooperation for collective benefits may falter. A reliable floor of support and protection is needed.

One means seems to be to continue to scale-up and increase confidence in the already discovered (cf. Weinberg's (1970) spectroscopy) while simultaneously working toward new discoveries. Another means is to continue a highly planned and regimented program (perhaps 50 percent of resources) and yet retain an investment resource for problem-oriented responses (David 1973:21). The latter responses keep the agency relevant but slow the fundamental progress. The mix is what is so critical. Our observations are that there is more of the latter than the former. While relevance to brush-fire management problems is gained, the research system is imperiled for the future and is thus unstable.

A strategy for allocating research funds based on a percentage of the gross budget is inflexible and may prohibit a wise allocation. Research must be brought into the total parkland agency budgeting process in a responsible, sophisticated fashion.

4. Multiple research agencies are needed. However, no duplication in efforts in the system should be allowed. Competition may be permissible, but such competition should be formed in debate and computer simulators should be used *prior* to initiating research.

5. Manpower must be managed, not only to protect years of investments in developing mastery of a body of knowledge but also to prevent inefficiencies, loss of interest, and professional stagnation. "Experience" provides little advantage in the atmosphere of an innovative research group. Educational programs are essential for individuals or programs to be competitive.

6. Among the multiple agencies there must be coordination. Minimized duplication should be one measure of success, the other should be that the perceived collective output should be significantly greater than the likely sum of the same agency's output if the effort has been uncoordinated.

7. The system must be cost-effective. Costs of total measurable output, of contracted output, of managerially relevant conclusions, and of publications, are some means for evaluation.

8. Projects must be phased. Expectations of immediate solutions to many problems are typically unfounded. Programs must evolve rationally. Many projects require years of persistent effort before they yield results. Simons (1966), quoting the 1963 Robins committee report, said National Park Service research "has lacked continuity, coordination, and depth. It has been marked by expediency rather than by long-term considerations."

A primary criterion of phasing is that planned work matches available funds and that the resultant system is reasonably stable. Kosik (1970) indicated that the amount of funding for research projects follows a log-normal probability distribution. We can expect outputs to follow a similar pattern. Partitioning of funds and plotting expected results by similar processes seems feasible.

By merging the existing COMPARE system (Bureau of Outdoor Recreation 1969) and its data on recreational projects (replacing these data with those on parkland research projects), with a log-normal analysis, a significant phasing aid can be obtained.

9. Specialties and diversity should be encouraged. Expensive tools of modern research are now out of the reach of some agencies. No agency or group can be comprehensive. Increasingly major universities and the federal government are the only agencies capable of supporting some research capital investments. Coordination is essential; rarely are such facilities used to capacity.

10. Information collection, storage, and retrieval systems are essential. There must be:

A. The electronic library, a means for optimum retrospective searching and which can be used to (1) find relations, (2) avoid duplication, (3) gain evidence, and (4) apply corrective feedback; and

B. A data base that is descriptive of (1) the users, (2) the physical and energy environment at any time and location, and (3) the relationship codes necessary to measure diversity and association. Grid data bases seem essential for parkland decision making and thus are an appropriate format and focus for research efforts.

Plans, of themselves, justify some degree of fiscal support. More importantly, they force thinking toward solving certain unavoidable problems. Plans reduce the impact of problems, increase efficiencies, reduce risks and insecurities, unify work, increase morale, and enable reasoned, low-cost changes when such are seen to be necessary. No agency or activity (such as research) can advance or maintain its position in a competitive environment today without long-range plans. Henderson (1973) said "to suggest that research is a form of intellectual endeavor that cannot be planned is to take an extremely elitist view of what research is, to do a disservice to science, and to invite boondoggles, masquerading as research." Nichols (1971:33) quoted Harvey Brooks saying ". . . today our felt need to plan too far exceeds our understanding of how the system of science and technology really operates." Nevertheless, it will not get better by itself, miracles are not in the offing.

11. A system must have a transmittal and transforming function. It must transform research results into decision criteria for management. Managers must be given answers and techniques they cannot easily refuse. To achieve this, there should be a subsystem including not only educators but behavioral scientists whose job is to "modify" manager behavior , i.e., to make cost effective use of discovery . The scientist must assist, but rarely will his talents be maximized under the burdens of getting out the results to all potential users. This requires an environment of available start-up capital, technical support (e.g., computer programmers, mechanics), a healthy agency attitude toward risk-taking, an appropriate agency regulatory atmosphere, and circulated managerial reports of successes and failures.

It is not too much to ask for, but perhaps too much to expect that this transformer unit can exist amidst new understanding between

manager and researcher. Call it cooperation, tolerance, or respect but the agency must avoid asking too much of the researcher. Whether treated by modern medicine or a witch doctor, in some situations the chief's son may die. The researcher cannot cure all ills. There are limitations to his craft. He can produce answers of variable correctness but they must be tested. The scientist has a fair question for the manager critical of his answers: Have they been tried? If so, is the fault with the practice or the practitioner? He can raise questions but they must be taken seriously. The manager or on-site decision maker also needs understanding for he must deal with whole-system decisions. He must decide before all the facts are in (they never are), and he must take risks far greater than most scientist are prone to take in decision making (i.e., $P \leq 0.05$). The thrust of past research has been toward increasing refinement, subtlety, and qualification; whereas, the manager and administrator must act with only very gross information. These pathways have been diverging. They can be made parallel. The scientist may not be the best person to judge the social utility of his own work. The manager may not be able to see all of the consequences of his decisions. Working together they can experience more than additive benefits.

Shannon (1969) said that public information systems are needed that portray the 3-P's of the ongoing research sytem: progress, problems and prospects.

12. In addition to the feedback to the research system that comes from the positive reactions of those that benefit from research, other feedback is needed. The annual appropriation process is the only major vehicle of research oversight now operating in wildland research. Feedback is needed in (a) personnel selection and rewards, (b) annual reports, (c) emphasis on objectives, (d) ombudsmen, (e) coordination and referrals, and (f) performance indicators as part of accounting systems. Feedback is needed in the form of research on the research system itself, for example, in project selection, library usage and speed, fund allocation, the fit between theory and practice, and optional research design. Research groups, like working scientists, understand their processes about as well as a centipede understands how it walks. A feedback "signal" is needed that prevents or deters adopting practices on the land, derived from research findings, before the consequences of their use are examined. Simulators can allow the management agency at least partial mastery of potential uses, rather than turn all techniques over to social choice. "Because *we can* does not mean *we must*" is a slogan useful in the boundary zone between discovery and application.

The "orthodox model" is a problem for a research feedback subsystem. ". . . there is a serious danger that the constant repetition of what is in truth merely a set of a priori assumptions (however rational, plausible, or otherwise commendable) will in time become accepted dogma that the unwary may critically accept as established fact or as an unescapable logical requirement. There is also the danger inherent in all established dogmas that the surfacing of contrary opinion and evidence will be resisted in every way" (de Vaucouleurs 1970:1205).

12. A research system must have a feedforward component. Feedforward is the action that makes a system optimal over the long run. It is comparable to leading the target, in hunting. It implies that a less-than-desirable state may be created for the present so that over the planning period maximal results will occur. This role can be achieved by simulators, scenario builders, and working with futurists.

To meet these 13 criteria is not, in most cases, merely a question of increasing efficiency of present research. To meet some of the criteria, changes may require fairly radical action. Collectively, the results can be difficult and hazardous, like stopping a car on an icy road. Following the anology, the alternative is a smooth ride . . . but off a precipice.

APPROACHES

The scientific method has served man well. There are new approaches that do not replace it but expand and complement it. In parkland research (as in other research), the emphasis on a deductive approach has proven useful. A model of the general realities of an ecosystem or a social system can:

(1) Allow nondestructive research on the system (e.g., "If I choose roadway site A, what will be the consequences?" "What if I choose roadway site B?");

(2) Allow sensitivity studies of a system so that research can be devoted first to those factors over which managers have greatest control and the changes which cause the greatest change in ecosystem performance. We have developed such systems for deer populations (Walls 1974; Hoecker 1976), rabies (Smart 1971), and power transmission corridor location (Jones 1976);

(3) Become the end-point of research to improve knowledge of a park system.

Research funds are often allocated to regions. As the characteristics of regions change (e.g., animal populations, use rates), a fixed allocation becomes suboptimal. We have a computer system for forming homogeneous regions. By using the program, regional boundaries can be changed to optimize this allocation problem.

Giles et al. (1976) have developed a statewide environmental information system for use in corridor location. That system can now be used for spot location, land use planning, and many other purposes. The system becomes a repository of information as well as a user of research relations. For example, the total solar radiation or the net radiation in any set of cells in the entire state can now be computed as a function of map coordinates, slope, aspect, time and cloud cover (Lawrence 1976). These calculations are based on syntheses of the available open literature of the scientific community. Other maps can be similarly computed. The map becomes the format and the target for many types of research output, both environmental and social.

Large computer models of cities (Forrester 1969), states (Smith 1973), and the world (Forrester 1971) now exist. These or related models can be created or modified to determine the likely results to parklands of (1) oil embargoes on parkland travel, (2) acid rain effects on parks resulting from lifting bans on burning sulfurous coals, (3) reductions in growing season length from increasing particulate air pollution in the 4,000+ meter zone due to air quality standards requiring taller stacks, (4) earth warming, and (5) new urbanization resulting from fossil energy shortage and/or price changes. We think these are both legitimate research activities (i.e., hypothesis

formation for later societal testing, computer aided system description, and nonphysical "pilot" studies). We think they provide essential knowledge about the context within which the parkland research system is likely to exist, the relevancy of some research, and the administrative strategies required if a parkland system will exist at all.

There are few good examples of the feedback and managerial control that a research system can provide to itself or the parkland system. A powerful one, however, is MAST (Management Activity Selection Technique) by Lobdell (1972). This system, operated for state wildlife agencies by the Division of Federal Aid, Fish and Wildlife Service, assists them in optimal allocation of their budgets to achieve their stated objectives. Deviations from an optimal state may be flagged and justifications sought. The system specifies needed data, clarifies the factors that "make a difference" in the decision (implying needed precision in data collection or research), and provides long-term concepts for the annual decision.

Computer systems are now available for aiding in achieving the parkland research system we have described. The MAST system, a linear programming approach, can probably be used, relatively unmodified (Lobdell, pers. comm.). Bethune and Clutter (1969) demonstrated that dynamic programming could be used to allocate research funds to maximize dollar returns from the forests of Georgia. Claxton and Rensi (1972) and Rensi and Claxton (1972) have developed a zero-one integer programming approach to research fund allocation in the U.S. Forest Service and related agencies. The COMPARE system of the Bureau of Outdoor Recreation (1969) and Efeval (Giles, unpubl. data) are "maximizing" selection strategies, using an objective weighting approach.

The system we propose would utilize concepts from the above. It is not a one-school approach but best described as *heuristic*. Several optimization procedures are run simultaneously on the same data and displayed in a table. The reason for this indefinite approach is:

(1) The goals and objectives of research fund administrators are not fixed and are not likely to be very soon;

(2) Even if they were, they are changing;

(3) Where several methods suggest the same "right" answer, confidence and justificatory power are gained. The cost is high, but "high" is relative. A computer run of hundreds of dollars after days of person-hour input is small relative to the input costs and nearly zero relative to the total research budget, small relative to the "savings" from avoiding suboptimization, and closer yet to zero relative to the long-term total benefits per dollar invested in the allocation process itself.

The goals that are likely candidates for a parkland research system (each subject to a set of constraints) are:

(1) To maximize the sum of the probable benefits (e.g., as scored Shumway and McCracken 1975) over x years.

(2) To maximize the sum of probable benefits over x years per present-discounted, 1976, dollar invested.

(3) To maximize the number of conclusions (or pages of publications) per present-discounted, 1976, dollar invested.

(4) To maximize the 1976 dollars invested in high-score (Table 1) research.

(5) To minimize the expected cost differential (or benefits foregone) over y years to the system of operating without the research having been funded and the research being funded (an opportunity cost approach).

(6) To maximize the probable use-citations of project-research publication per present-discounted, 1976, dollar invested in research.

(7) To secure the highest probability, over time, of achieving a set of weighted objectives (Table 1) with a fixed budget.

These are subject to constraints such as personnel, budgets, research type diversity, area distribution, research program stability (variance), and output of the transformer unit.

As always, it is one thing to establish goals and quite another to attain them. Without them, however, there is little incentive to develop solutions or to expend creative efforts. "To understand nature" will no longer suffice as an objective. When will we know that we do?

The inputs to the research allocation process are typically guesses and estimates. They are statements of perceived probability variously arranged and computed to produce the allocation decision. It is unlikely that this will change. In fact, overemphasis on data and costly analyses of past activities is inappropriate. Therefore, there is not a major need for new inputs but improved means for processing the information, estimates, and values now used. The needs are for aids to articulating the assumptions, making explicit the estimates, and properly accounting for the interactions of the complex resource system. Our hypothesis is that it is beyond human mental capability to consistently process all of the factors in Table 1 and select projects from among hundreds of proposals those which are demonstrably superior. We propose that time spent by agencies in directed analysis (the pattern of Table 1) will be well-spent.

The research allocation system we now see as being appropriate for complex parkland problems is one that uses a simulator to answer, "What if project q is funded?" and "What if the set of projects, Q, is funded?" By using a stochastic "success" component of the model (Gaver and Srinivasan 1970; Shumway and Hwang 1975;32) the likely performance of the parkland system under the various influences of each research project can be estimated (cf. Djerassi 1973). The result is a goal programming system used in an iterative simulation mode. The results are tabular decision aids. The computer can be programmed to make the allocation decisions but we prefer it not replace the decision maker, only provide substantial aid, help reduce risks, and give him more time to plan, assess values, and convert the results of research into benefits for mankind.

TABLE 1. A computer program can be employed to compute a score, for a proposed project based on probability statements or proportions estimates from experts on the following topics (and compared to those of the proposal writer). High, moderate, and low estimates are requested for each entry and a better distribution used with each.

Project Realm

Research need category (from agency list)

Relative perceived importance of research category (from agency list)

The proportion of the project judged to be new and unresearched

The proportion of the project judged to be expanding, extending, or clarifying previous work

Proportion of gross research budget requested

Response to documented managerial or administrative need

Program research (planned)

Venture research (not 2 or 3)

Probability the research is consistent with or falls within agency policies and research directives

Proposal Quality and Type

Clarity and explicitness of likely results as articulated by researcher (scale of 0 to 100, 100 being maximum)

Probability project would be judged bold and unorthodox by a panel of scientists

Probability the proposed research is judged original by a panel of scientists

Probability that the project's simplicity is judged high by a panel of scientists

Probability that the project's theory is judged beautiful by a panel of scientists

Probability the results will provide predictive power or equations

Probability that the explanatory variable domain has been adequately sampled

Probability that the sampling frame will lead to generalizations of the scale needed (expressed in justifications)

Probability that the results will provide new descriptive or explanatory power

Probability that the results will provide clarity to present knowledge

Proportion of proposal in appropriate format

Probability of creating a significant new methodology, technique, or technology

Total techniques etc. likely to be created

Probability that a general system will result, applicable in not-related fields

Probability that a general system will result, applicable in closely related fields

The Researcher

Probability that the researcher is the best qualified among U.S. scientists to perform the research

Probability that the researcher's experience and training are pertinent to the proposed investigation

Approximate number of other researchers capable of performing the research

Probability that the total funds requested are within 10% of at least one project previously administered by the researcher

Probability that the researcher's objectives for this project will remain substantially unchanged (based on past project performance)

Probability that the researcher will achieve the written objectives (cf. past output, education, experience)

Probability the researcher will live to complete the research
    Researcher's sex (used to compute life expectancy)
    Researcher's present age

Probability that another researcher in the organization would satisfactorily complete the research if the researcher moved or died

Probability that the researcher will move or accept another job in the project period

Probability that the decision making group will remain constant over the proposed research period

Research Environment

Probability of positive interactions toward proposal objectives with local researchers.

Probability of available supportive facilities equipment, and resources.

Proportion of proposed budget in facilities and major equipment.

Distance of researcher from phenomenon to be studied (sum total travel distance for all trips for each year.)

Research Period

Probable years before conclusion will be reached.

Probable years before direct observable application or use is made of conclusions.

Probability problem will significantly diminish or disappear before time specified in 5 above.

Probability the subject or phenomenon will disappear if research funding is delayed 1 year.

Probability the subject or phenomenon will drastically change or diminish in 3 years.

Probability that subsequent research must be done before the results become useful.

Probability that such research will occur within z years.

Probability that the solution depends upon solutions or technologies not now available.

Probability that these solutions or technologies will become available for achieving project objectives.

Probability the results will be useful over a long period (greater than 10 years).

Probability that subsequent research funds (continuation funds) will be sought for these objectives.

Probability that continuation funds will be available.

Probability research will be applicable over a broad area.

Total area (in km^2) where likely applicable.

Probability results will be used in more than one ecosystem.

Probability results will be used in more than one parkland agency.

Other Influences

Probably number of people likely to be influenced directly (or indirectly by the area on which used) by application of conclusion.

Probability life quality of median individual (in 25 above) will be significantly improved.

Probability study conclusions will create agency strife (internal, inter-agency, or political).

Probability of adverse social consequences of project results.

LITERATURE CITED

ABERT, J. 1972. Since grantsmanship doesn't work, why not roulette. Saturday Review, October 21, p. 65-66.

ACKOFF, R. L. 1962. Scientific method: optimizing applied research decisions. John Wiley & Sons, Inc., New York, N.Y. xii + 464 p.

BETHUNE, J. E. and J. L. CLUTTER. 1969. Allocating funds to timber management research. Forest Sci. Mono. 16. 22 p.

BUREAU OF OUTDOOR RECREATION. 1969. COMPARE: A system for optimizing federal and federally assisted programs. Phase 2: Recreational development analysis, U.S.D.I., Washington, D.C.

BURGERS, J. M. 1975. Causality and anticipation. Science 189: 194-198.

CLAXTON, H. D. and G. RENSI. 1972. An analytical procedure to assist decision making in a government research organization. Pacific S.W. Forest and Range Exp. Sta., Berkeley, CA, USFS, PSW-80, 20 p.

DAVID, E. E., JR. 1973. Toward a National Science Policy. Amer. Sci. 61:20-23.

deVAUCOULEURS, G. 1970. The case for a hierarchical cosmology. Sci. 167:1203-1213.

DJERASSI, C. 1973. Research impact statements. Science 181:1.

FORRESTER, J. W. 1969. Urban dynamics. M.I.T. Press, Cambridge, Mass. xiii + 285 p.

FORRESTER, J.W. 1971. World dynamics. Wright-Allen Press, Inc., Cambridge, Mass. xiii + 142 p.

GAVER, D. P. and V. SRINIVASAN. 1970. Research and development coordination as a probability process. Management Science Res. Rpt. 193, Grad. School of Industrial Admst., Carnegie-Mellon Univ., Pittsburgh, Pa., 10 p. (NTIS AD 711835).

GERSHINOWITZ, H. 1972. Applied research for the public good--a suggestion. Science 176: 380-386.

GILES, R. H., JR., A. B. JONES, III, and C. W. SMART. 1976. POWER: A Computer System for Corridor Location. Office of Biological Services, U.S. Fish and Wildlife Service, Washington, D.C.

HACKERMAN, N. 1974. Ignorance as the driving force. Science 183: (Editorial)

HENDERSON, U. V., JR. 1973. Research planning (letter). Science 180:448.

HOECKER, S. W. 1976. NATAL: A computer based educational unit on white-tailed deer bio-energetics, Unpub. M.S. Thesis, VPI&SU., Blacksburg, Virginia, vi + 163 p.

JONES, A. B., III. 1976. POWER: A computer information system for land use decisions. M.S. Thesis, VPI&SU, Blacksburg, Virginia. vi + 193 p.

KOSIK, E. 1970. Log-normal distribution analysis of the aerospace research projects. U.S. Air Force, Office of Aerospace Res., Special Report ORA-70-0004, Holloman Air Force Base, New Mexico. vii + 33 p.

LOBDELL, C. H. 1972. MAST: A budget allocation system for wildlife management. Ph.D. Dissertation, VPI&SU, Blacksburg, Virginia. vi + 227 p.

NICHOLS, R. W. 1971. Mission-oriented R & D. Science 172:29-37.

RENSI, G. and H. D. CLAXTON. 1972. A data collection and processing procedure for evaluating a research program. Pacific S.W. Forest and Range Exp. Sta., Berkeley, CA. U.S.F.S., PSW-81. 18 p.

SHANNON, J. A. 1969. Science and social purpose. Sci. 163:769-773.

SHUMWAY, C. R. and J. D. HWANG. 1975. Resource in R & D: An operational quantitative approach. R & D Management 6(1):

SHUMWAY, C. R. and R. J. McCRACKEN. 1975. Use of scoring models in evaluating research programs. Amer. J. Agric. Econ. 57(4): 714-718.

SIMON, H. A. 1973. Relevance-There and here. Science 181(4100):1 (Editorial).

SIMONS, H. 1966. Science: sense and nonsense. BioScience 16(9):607-608.

SMART, C. W. 1971. A computer model of wildlife rabies epizootics and an analysis of incidence patterns. M.S. Thesis, VPI&SU, Blacksburg, Viriginia. ix + 125 p.

SMITH, J. L. 1973. An analysis of the environmental stability of Virginia. M.S. Thesis. VPI&SU, Blacksburg, Virginia. 229 pp.

WALLS, M. L. 1974. A dynamic white-tailed deer population simulator and lessons from its use. M.S. Thesis. VPI&SU, Blacksburg, Virginia. 167 pp.

WEINBERG, A. M. 1970. The axiology of science. Amer. Scientist. 58: 612-617.

PREDICTING IMPACTS OF PROPOSED FACILITIES IN PARKS[1]

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Even though parks connote wildness and low disturbance, they are continually being modified from within by those who seek to improve sanitation, communication, transportation, and use; and from without by those who see them as military or communication facility sites, places for roads and power transmission corridors, airports, criminal barracks, and the yet undreamed. Their undeveloped nature makes them targets for facility locators seeking to avoid the conflicts and costs of developed areas.

NEPA and related state laws legislate what was done by wise park managers years ago. Every facility, every option for a facility, was studied as much as feasible before it was actually built. There were excellent facilities built that were well-placed, attesting to that wisdom. There were some built that were not so well-placed. In the future there will be the same old reasons and some new ones why facilities must be better located than ever before. They include:

1) There are fewer suitable areas. The "good" ones have been used up.

2) The costs, especially long-term interest operation, and maintenance, are very great. Optimum allocations of funds are desirable.

3) There are fewer available funds.

4) There are more people influenced by well-located facilities; the benefits accrue rapidly. Conversely, so do the disproducts of poorly located facilities.

5) There are more people who are better educated and more critical of poor location.

6) There are improved monitoring devices, systems, and technology for assessing impacts and changes. We are more sensitive to the disproducts of poor site selection.

7) There are existing ways for rational and optimal location of facilities. It seems like a good idea to use the best techniques if they are readily available and feasible. Not to have done so, whether judged in court or not, smacks of malpractice.

THE ANALYSIS

There are two major phases to the facilities location problem. The first is answering the question of need; second, the question of location. Surprisingly, the two are usually mixed and confused. Our concept of a facility is a physical means that is used to achieve the previously established goals or objectives of park users. The question of need should be largely independent of location. It is only reasonable to ask: Is facility X needed in vicinity Y? The exact location of X is not yet in question. The question of need is best defined in terms of net energetics (Odum 1971; Odum and Odum 1976).

The question of location is only relevant if a positive decision is made for need. Once need is demonstrated or decided upon, then the developer can embark on minimizing impact or cost. What is a minimum cost facility? No facility! We know of no non-impacting facilities. A reasonable approach once a facility will be built is to find minimum impact sites. The objective is not to find the best, but the least bad site.

To do this, the basic questions are:

1) What are the relevant types of impacts or "social costs?"

2) What are the factors that cause such impacts to vary?

3) What is the relative importance to the decision maker (i.e., society, park users, select panel, or other) of each type impact?

4) What changes occur in the factors over the economic life or expected duration of the facility?

5) What are the likely consequences (e.g., ecological, political, employment) of making a wrong decision?

We think the above questions are fundamental to facility location anywhere, and especially in highly prized parks. A general methodology exists for answering them simultaneously. The methodology is now well-known. The application to park facility siting is new, and is essential if the well-recognized complexities of park systems are to be treated effectively. The problem analysis and the configuration of the solution system is new. Newness of the technique is not our key emphasis, only that a realistic, functional solution is available to solve massive park problems.

THE METHODOLOGY

Type of Impact. Each facility has a set of types of impacts. Impacts are: (1) on-site; (2) off-site; (a) onto the site, (b) from the site; (3) probable impact (an expression of risk); and (4) temporal. A power transmission line across a park has the 12 types of impact shown in Table 1. An airport has a similar type of impact. These are named *costs*. They are the typical categories used by the public to express

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losses and impacts. The cost list does not have to be an exhaustive list. It is a list of "significant" impacts where significant means that any conceivable decision would not change if another type of impact was included in the list. "Land use classes" is an inappropriate substitute for "types of impact" or "environmental costs." It tends to exclude construction costs and may ignore such types as "visual impact," not typically a land use type (unless defined as a viewscape).

TABLE 1. Twelve "dimensions of impact" employed within the computer analysis. Weights are assigned each. Impacts are computed from interactions of 41 variables over 30 years on these weighted dimensions of the location problem.

1.	Construction and maintenance cost
2.	Scenic and visual
3.	Vegetative change
4.	Wildlife community
5.	Aquatic community
6.	Recreation utility
7.	Historic
8.	Residential use
9.	Agricultural use
10.	Forestry
11.	Institutional use (schools, etc.)
12.	Industrial use

Factors. "Type" qualifies impact; "factors" allow the types to be quantified for each site or decision alternative. The factors used in Virginia high voltage power line siting are those in Table 2. Each of these may operate several times in describing other factors as well as types of impact. "Elevation," for example, may influence or be a part of the computations of (a) slope, (b) aspect, (c) visual impact, (d) agricultural impact, and (e) construction costs.

Solar inputs to a cell, for example, can be computed. This is a complex algorithm relating slope, aspect, location, and cloud cover (Lawrence 1976). Visual impact of most facilities can be analyzed from all points (cells) from which the facility may be seen. The facility is the visual stimulus. There are several ways to compute this impact for an environmental impact statement or court presentation. The most feasible may be selected and justified, or several used and presented, particularly as they may reinforce each other. These include using:

1) Public view points such as overlooks. This is a limited approach and such sites are ephemeral.

2) Roads and public sites such as historic sites and recreation areas.

All of the places (map cells) in which a facility can be seen from roads and such sites are tallied. The relative visibility of a facility for any position on a map can thus be computed and displayed. It can be presented as a score, the probability of being seen from all cells in a map, or the visibility relative to the most conspicuous cell in the study area.

To handle large numbers of factors and the computations required, both a data base and computer are required. Computer usage can now be arranged for in all federal and state agencies. Data bases exist in a dozen states. A data base such as described herein can be developed for long-term use for the largest U.S. park for less than $100,000.

We presently have coded data over 100 variables for every 27 acre (1/9 km^2) cell in a large proportion of Virginia. At present all of the data are taken from USGS topographic maps (7½ minutes; 1:24,000) and from maps of data from various agencies such as the Division of Outdoor Recreation. We are developing capabilities for using Landsat data. The cell size is only significant as it relates to cost. Halving any cell size more than squares the cost. The park decision maker must create a balanced data set for each decision. It should not be more precise than the lowest quality datum. It should accommodate the variances likely over 20 or more years in most cases. Great accuracy is usually very costly, delays decisions, and may not be rational given the imponderables of the accuracy of multiple data sources, monetary interest rates, and changing social values.

We shall present the other aspects of the impact analysis process, then show examples of how it is implemented within a park or used to defend a park from intrusion.

The problem is analyzed, types of impact listed, factors analyzed and decided, then maps for each of the types are computed. These can be presented as computer maps, or tabular output.

The relative value of each type of impact is next determined. This is the process in the system where sociology and ecology are wed and where "politics" can be included.

The decision maker establishes the most important type of impact in the list and assigns it a weight of 100. This is the impact of greatest value. He weights all other types of impact relative to this. These are weights, not ranks, and have been called shadow prices. They provide the means for converting numbers to a common unit of desired benefit and therefore provide the means for adding "apples and oranges."

Another difficult decision is: Who is the decision maker? The analysis system proposed here does not discriminate. It can be a dictator, a board, a representative body, a voting public, or a random sample of the public. In some cases, the decision maker will not assign weights. There are risks in doing so; the process identifies explicitly the value system employed; it defines the personhood of the decision maker, an image always well-guarded. One option to avoid these risks is to display exaggerated weighting systems, e.g., the super preservationist-esthete; the all-around citizen; the short-term personal profit maximizer. By presenting three solutions based on such weights, the differences can be compared. Our experience with power-line location shows that routes are identical over much of the terrain because of interactive constraints. The evident divergencies focus attention on the meaning and

TABLE 2. Critical characteristcs pf the *Power* system. These factors may be operative interactively and over time.

1. Total depreciated likely construction costs (1973)
2. Cell observability
3. Large streams
4. Small streams
5. Lakes and ponds
6. Swamps
7. Wooded marsh
8. Submerged marsh
9. National Forest
10. Miscellaneous forest
11. State-owned natural resources
12. Orchards
13. Agricultural field
14. Residential area
15. Urban area
16. Slope class 5-15 degrees
17. Slope class greater than 15 degrees
18. Registered historic sites
19. Recommended historic sites
20. Proposed historic sites
21. Existing public parks
22. Potential public parks
23. Existing public natural areas
24. Potential public natural areas
25. Existing private non-commercial recreation areas
26. Potential private non-commercial recreation areas
27. Existing commercial recreation
28. Potential commercial recreation
29. Existing scenic easements
30. Potential scenic easements
31. Potential recreation resources
32. Existing major hiking trails
33. Proposed trails
34. Existing boat landings
35. Existing beaches
36. Potential beaches
37. South - facing slopes
38. South-west facing slopes
39. Ridge tops
40. National park
41. Cell observability from roads and historic sites

TABLE 3. Relative impacts of a high voltage powerline across Northern Virginia.

Powerline corridors	Total corridor impacts	Corridor impacts to park only
Corridoe proposed by utility company	3.6	0.42
Optimal corridor selected by POWER system	1.0	1.0

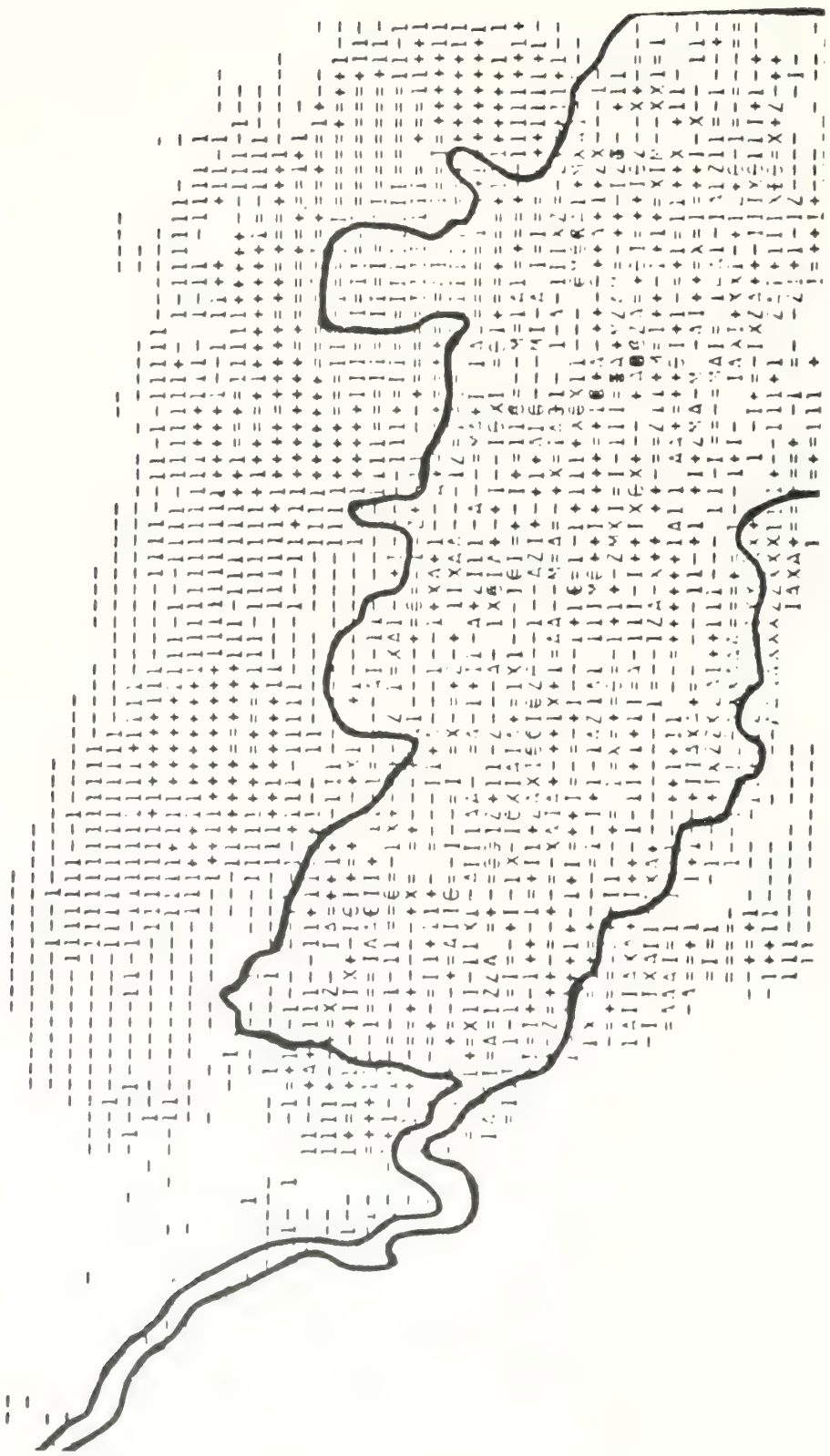

FIGURE 1. Computer generated map showing visibility from potential sites. The darker the symbols the more highly visible the cell is from surrounding cells. Visibility is calculated for a three mile radius from each cell.

implications of these extreme value systems.

Curves of ecological succession and physical processes after facility construction can then be used to accumulate impacts and changes over time. Cumulative impacts over time become an appropriate criterion for making relative comparisons of alternative routes or sites.

We have used a data base on the Shenandoah National Park to locate a hypothetically proposed educational center that minimizes trail building (i.e., is near existing roads) from which many cells can be seen, is on low-impact sites (i.e., low slope, northerly facing), and near a stream. Fig. 1 is a computer-generated map illustrating visibility from potential sites in the park. The optimum potential sites for the center using the objectives listed above are shown in Fig. 2. Note that we specify objectives, not constraints. This is a positive approach which, once used, can then be utilized with constraints.

We used an *opportunity cost* approach in one application of our system. Where land values are known, then a minimum monetary route can be determined. Then we study the increase in cost required to move around a park, historic site, wetland, etc. This method avoids the need for pricing a wetland but implicit in the method is "this wetland must be worth *at least* Q dollars if it is rational for society to go around it." (See Giles et al. 1976).

We have also used the system to demonstrate how the difference in a proposed power line route across the park can be compared to the cost of the optimal route across the park. The point we raise here is that the system can be used to select optimal routes but there will still be a decision that must be made. Fig. 3 shows the global optimal route and the proposed route within the park. Table 3 shows that the impact *to the park* is 2.4 times greater when the optimal route is selected, but the total environmental impact of the overall computer-determined optimal route is 3.6 times *less* than that proposed by the utility company. The nature of the problem is shifted and the questions for the park manager made difficult for then he must argue for *park* protection or the total overall good from the siting decision.

On the park itself a road, trail, or utility corridor can be readily located and *the* optimum path, given the data, can be readily determined (at costs, if a system is operated out of a regional office, of less than $50 per decision).

The system we have developed, used, and made internationally available can be a dynamic state of addition and improvement, and can provide the format for a well-planned, optimally allocated system of parkland research. It provides a system dependent on such research and by which such research can be readily transformed into benefits for man.

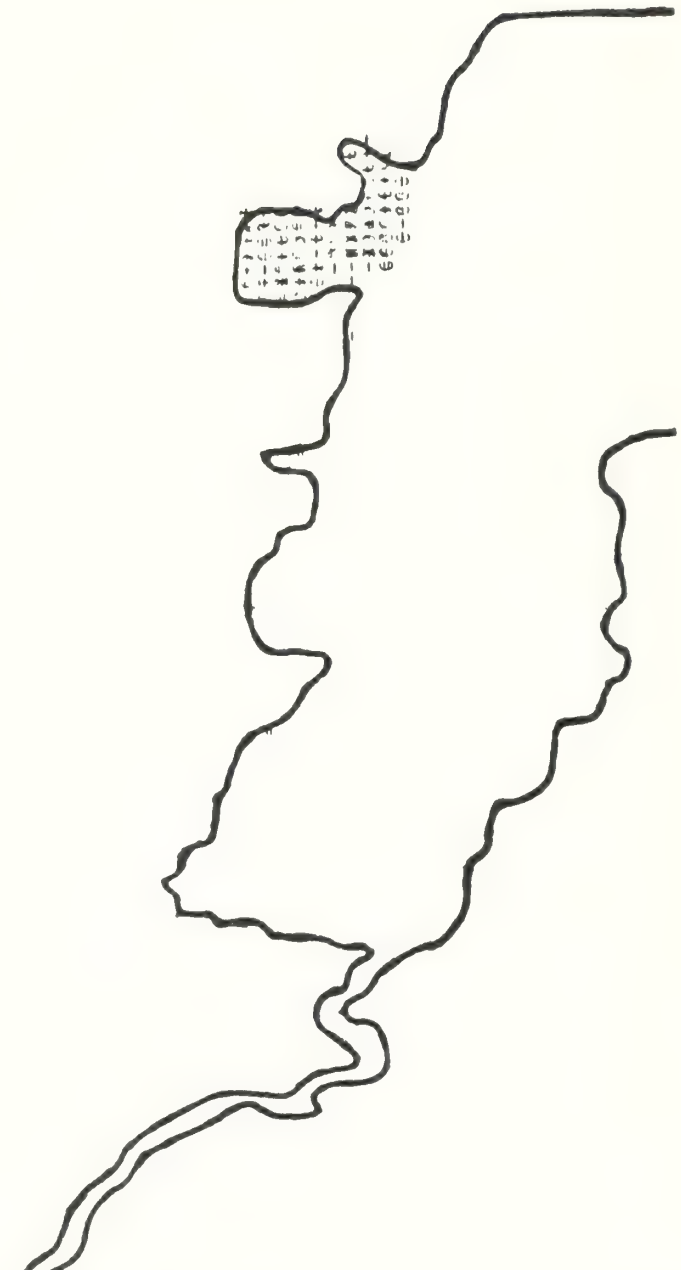

FIGURE 2. Computer generated map showing potential sites for the center. Cells represented by darker symbols better satisfy the combined objectives.

LITERATURE CITED

GILES, R. H., JR., A. B. JONES III, and C. W. SMART. 1976. POWER: A computer system for corridor location. Office of Biological Services, Fish and Wildlife Service, U.S. Dept. Interior, Washington, D.C.

LAWRENCE, G.E., JR. 1976. A computer-based insolation mapping algorithm for large areas. Unpub. M.S. Thesis, VIP & SU, Blacksburg, Va.

ODUM, H. T. 1971. Environment, power and society. Wiley-Interscience, N.Y. ix + 331 p.

ODUM, H. T. and E. C. ODUM. 1976. Energy basis for man and nature. McGraw-Hill Book Co., Inc. N.Y. x + 297 p.

FIGURE 3. Computer generated map illustrating the route proposed by the utility company (straight line) having minimal impact on the park and the computer determined route considering minimal impact to the region as a whole.

THE USE OF SIMULATION MODELS IN PROJECTING POTENTIAL VISITATION TO NEW NATIONAL PARK AREAS IN ALASKA

R. Gerald Wright[1]

INTRODUCTION

The need for obtaining accurate estimates of potential numbers and types of visitors to national parks is well established. Operating budgets, manpower needs, future development requirements all hinge to a great degree on this very important factor. For many years, visitation to parks, in general, steadily increased, so that even if nothing else was certain, one would be relatively sure that the next year's visitation would be greater than the preceding year. Recently, however, large variations have appeared which have rendered past trend lines unreliable, placing a great burden on park planners who are faced with anticipating the future needs and development requirements particularly of new parks with unknown numbers of potential users.

In Alaska, where we are collecting data and doing preliminary planning for nine potential new areas, and additions to two existing parks, this problem is particularly acute. Here we are concerned not only with the numbers and origin (i.e., Alaskan or outside) of potential visitors, but the type of user and the distribution that might be expected among the new areas.

BACKGROUND

Data on potential use will play an important role in Congressional debates and other deliberations on whether or not any or all of the proposals become part of the system, and the management category they will fall under. As an instance, there are those in the state and elsewhere who support National Park Service involvement only to the extent that it will generate new economic opportunities to the populace in terms of increased tourism and increased expenditures for development. On the other hand, there are those who support it only to the extent that National Park Service management will continue to promulgate the wilderness quality of the land and limit extensive development and use. The lack of presently reliable future visitation forecasts makes it difficult to discern between these futures. It was for this reason that this study was initiated.

BACKGROUND METHODS

There are several traditional ways to predict the consumption of recreational facilities. The simplest and one used most often by National Park Service planners is to look at a time series of the number of visits to a given area (Clawson and Knetch 1966). Linear extrapolation of this trend line to future periods provides an estimate of the projected use. The estimates yielded by this technique may be quite accurate; however, they are useful only for short time periods, and of little use for new areas.

A variation of this method is to include certain causal factors, believed useful in explaining the variation in consumption, in a multiple regression equation. This technique has been used by the United States Outdoor Recreation Resources Review Commission (1962) to relate visits to national parks to per capita income, per capita leisure, and per capita mobility, and by Cheung (1972) for visits to Saskatchewan parks. Forecasts using this method must be carefully examined and interpreted (Wilkinson 1973), and they lack the dynamic qualities of other forms of analysis.

Another technique has been the use of gravity models (see, for example, Ellis and Van Doren 1966; Cesario 1973, 1974). The gravity model is based on the assumption that the number of recreational trips from an origin of a given population to a particular destination is a function both of the population size and the distance between the two points. Such models have been traditionally used for day-use local parks and have seen little use in predicting consumption demand of national parks. They have also proven to be generally inaccurate for very short and very long distances (Wilkinson 1973).

OBJECTIVES

The intent of this study is both to develop a working model which would help aid in predicting future visitation to the new Alaskan parks, and to look at the theoretical basis whereby the techniques of simulation modelling can be applied to visitor determination problems. One of the advantages of applying models to such problems is that the system structure as theorized by the modeller can be succinctly seen both in overview and through each of the explicitly stated relationships. Thus, the assumptions behind the model, as well as the form of, and presence or absence of a given relationship can be critiqued. If this paper does no more than to elicit critical responses from reviewers concerning the form and validity of such relationships, then both objectives will have been accomplished.

ASSUMPTIONS

The broad assumptions behind this approach are that park visitation can be ascribed to some function of the population of potential park users; that the level of use is in part determined by economic factors; and that the use of one area over another is influenced by the level of development in a park unit and the type and ease of access available to the visitor. These broad assumptions are in turn translated into more specific factors and discreet variables as listed in Table 1.

Resident and non-resident populations were considered separately in the model. It is also recognized that the majority of the Alaskan population is centered in Anchorage. The regional population included the combined figures for Oregon, Washington, and California, the three states which contribute the majority of visitors to the state. It was assumed that recreational demand could be looked at as a function of the age structure of the population. Three separate age classes were used; 0-20 years, 20-45 years, 45+. Each of these groups have in general, somewhat different desires, and are differentially affected by economic conditions, and level of park development. The economic factors are gross indicators of the economic health of the nation, and are combined in the model with a measure of fuel

[1]National Park Service, Anchorage, Alaska.

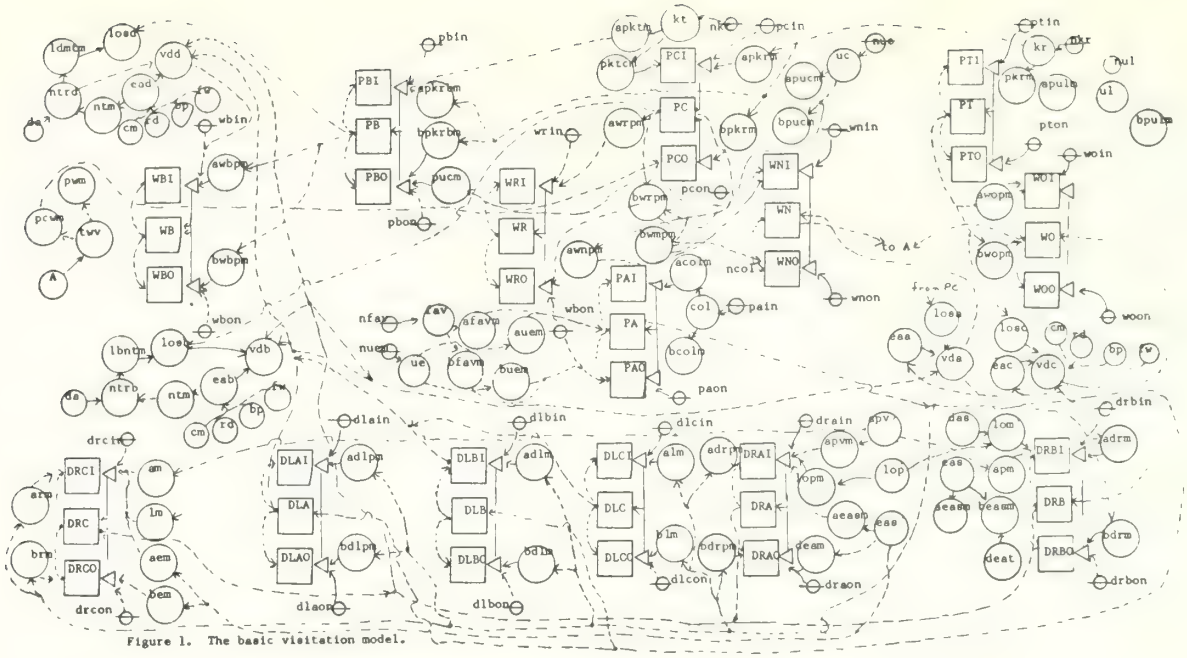

FIGURE 1. The basic visitation model.

availability to form a measure which might be termed "park affordability." Mueller and Guerin (1961) have found that such socioeconomic variables as income, age, and occupation explained about 30 percent of the variation on a scale indicating potential participation in outdoor recreation.

Studies considering the effect of site attractiveness and opportunity for use are not common (Cheung 1972). Clawson and Knetsch (1963) suggested the possibility of developing specific rather objective rating scales to measure the attractiveness of outdoor recreation areas. In this model, the attractiveness of a park was related to the level of development. Four types of park development were considered. The type of activities available were not included, because the range of traditional national park activities in the area studied was not limiting. The different development variables were combined into one overall measure of "park desirability" which was computed separately for each of the user groups discussed below.

Access was considered both as a function of the relative ease of and frequency of service from the outside and the ease and type of access available to the park area. Concerning this latter point, it should be recognized that road access is available to only a portion of one of the proposed new areas. Others were accessible by chartered bush plane and commercial airline.

Four categories of park users were considered and are summarized in Table 2. Resident campers are those whose activity is based on the use of self-contained campers or trailers; non-resident campers are considered to have a similar pattern of use. Resident and non-resident back-packers were combined as it was felt that both the pattern of use and factors affecting use are similar. The final category is those non-residents who visit the area as a part of an organized package tour. The output of the model is in terms of visitor days for each of the four user groups on a yearly interval.

MODEL STRUCTURE

The basic model structure incorporates the systems design concepts of Forrester (1961, 1971), fundamental to which is the concept that in establishing the structure of the system, all actions take place within feedback loops. Within these loops, the structure is based on two kinds of variables: states and flows. The states are real entities which describe the conditions within the system at a given point in time and consist of the above described user groups, population demand levels, and park desirability and affordability indicators.

The basic equation which describes the condition of any state in the system at any point in time is given below:

STATE = STATE		+ addition of material from other states	-	
time(t)	time(t-1)			
deletions to other states	+	internal growth	-	internal decay

The overall model is shown in Figure 1. This diagram follows standard format, with the squares representing the states, the squares with corresponding values--the input and output controls to and from the states, the circles the multipliers and associated variables, and the dashed lines the flows of information. Key to the model is the series of multipliers which relate variables of different measurement units to one another. The definition of terms and parameterized values are found in Appendices I and II. The model was run using DYNAMO software.

RESULTS

The model was parameterized for conditions at Mt. McKinley National Park, and the visitor use data there were used as an independent check on the validity of the model output. Fairly accurate visitor-use data are available for a seven year period between 1969 and present. Visitor use data are available for the park lodge, which

TABLE 1. Basic factors and variables considered in the model

Factor	Variables
Recreational demand level	Alaska population
	regional population
	age structure of the population
National economic factors	changes in the cost of living
	unemployment levels
	energy availability index
Level of park development	kilometers road development
	kilometers trail development
	units campground
	units lodging
Ease and type of access	distance from the park
	type of access to the park
	volume of commercial flights to Alaska
	percent of Alcan paved
Other factors	level of regional publicity
	length of stay

TABLE 2. Categories of users selected.

1.	resident	campers
2.	non-resident	campers
3.	resident and non-resident	backcountry users
4.	non-resident	members of organized tours

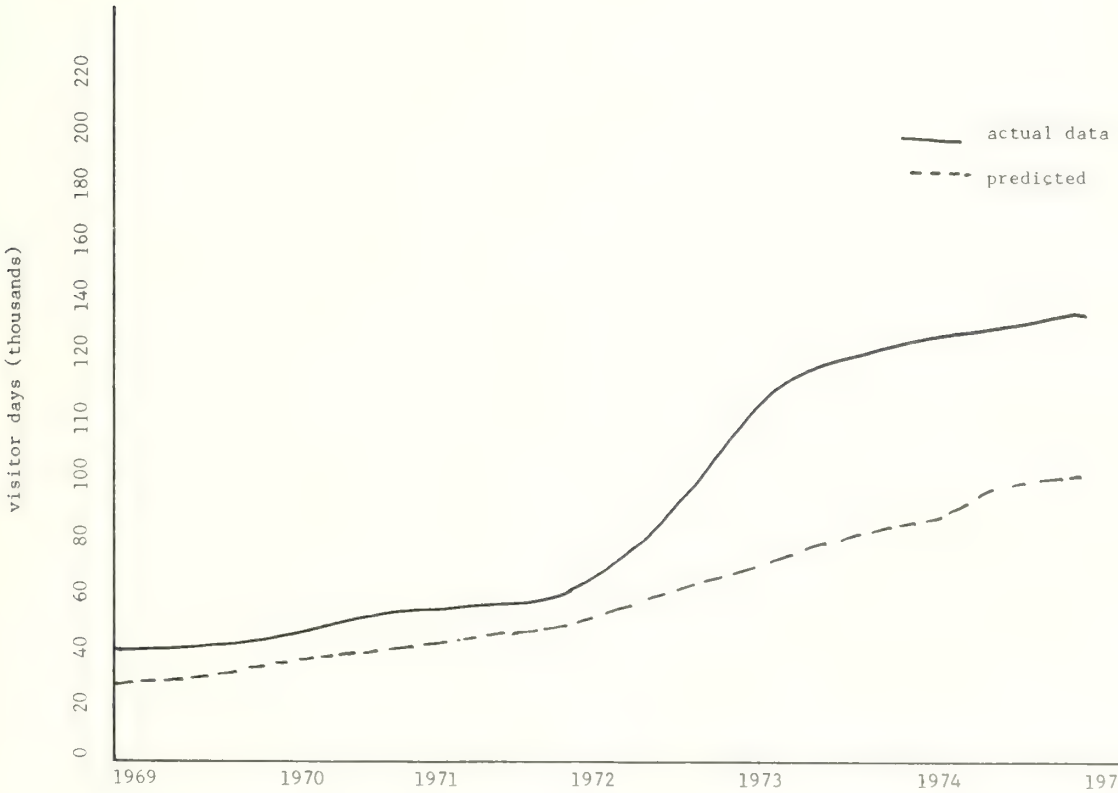

FIGURE 2. Comparison of actual data with that predicted by the model for backcountry use at Mt. McKinley National Park.

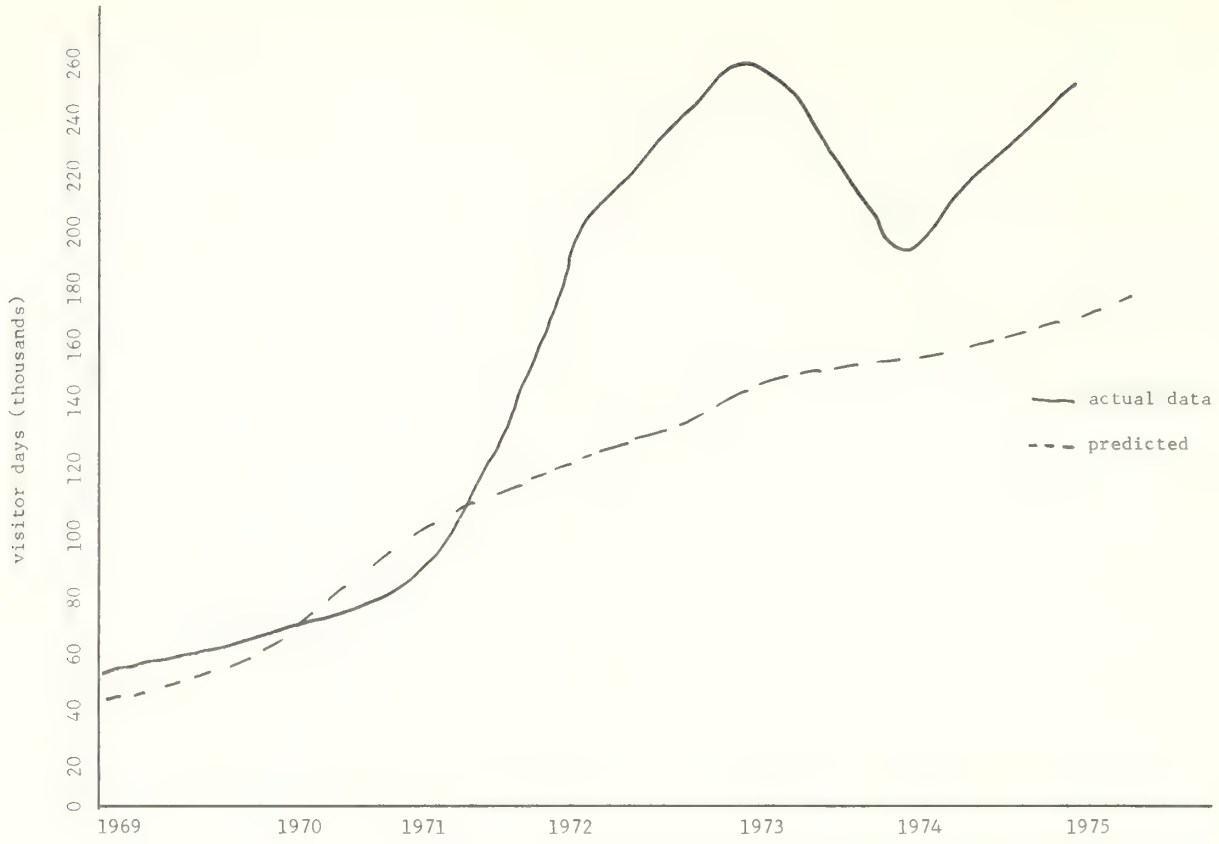

FIGURE 3. Comparison of actual data with that predicted by the model for resident camping at Mr. McKinley National Park.

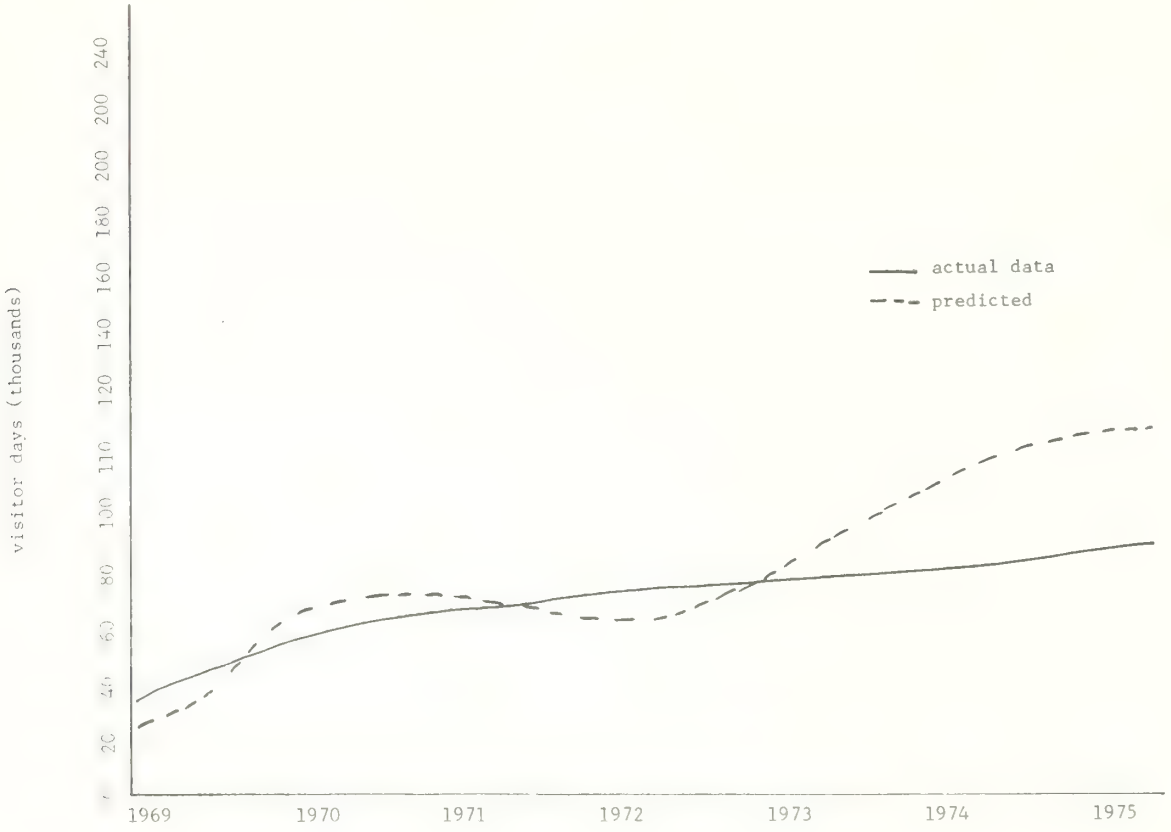

FIGURE 4. Comparison of actual data with that predicted by the model for tour group use at Mt. McKinley National Park.

was assumed to most closely represent tour group use; for backcountry use; and for overnight use of campgrounds. In the latter case, it was arbitrarily decided that 30 percent of the use was by non-residents.

A comparison of the reconstructed visitor use data for backcountry use with that predicted by the model is illustrated in Figure 2. In general, the model output paralleled the increase in backcountry use which actually occurred in the park over the time span indicated. It, however, failed to mimic the increase between 1971 and 1972 when use of the backcountry essentially trebled. The reasons for this increase are not clear. One of the future aims of this project will be to discuss with the park staff such anomalies in the basic data with the idea of understanding causality and thus improving model response. The model consistently underestimates the extent of backcountry use. The reason for this appears to be in the component of the model which calculates the non-resident contribution to backpackers.

A comparison of model output with actual data for tour group use is shown in Figure 3. Here the output shows an oscillatory trend; at times underestimating and at times overestimating the actual data. Although the mechanisms are being refined, the model appears to be more sensitive than is the actual case to increases in access to the state and to national economic effects as measured by the model. The model also appears to underestimate the constraints that limited park lodging has had on any increase in the use by tour groups.

Figure 4 shows a third similar comparison of the use of the park by resident campers. Here, the model while mimicking the basic trend, consistently underestimates the resident camper component. Part of this problem may rest in the arbitrary allocation of the actual data into resident and non-resident categories. It is possible that the resident camping component was overemphasized. No output at this writing is available for a comparison with non-resident camping users.

CONCLUSIONS

In general, the preliminary model is sensitive to the long-term trends which have actually occurred in the park, and insensitive to the sharp yearly changes which have occurred at different times. These sharp changes may be due to effects external to the model. Establishment of the reasons for these changes may help in refining the sensitivity and scope of the model.

Further refinement of the model is definitely necessary if it is to be useful and this is anticipated.

It is hoped that future work will allow the model to be used as a basis for comparing the potential visitation to the different proposed park areas in Alaska. To do this, the model will have to be expanded to include the different user opportunities available in each of the areas, and to include some measure of the overall character and aesthetic qualities which influence visitor perception and use.

LITERATURE CITED

CESARIO, F. J. 1973. A generalized trip distribution model. J. Reg. Sci. 13:233-248.

_____. 1974. A simulation approach to outdoor recreation planning. J. Leisure Res. 7:38-52.

CLAWSON, M. and J. KNETCH. 1963. Outdoor recreation research: Some concepts and suggested areas of study. Nat. Res. J. 3:(2).

_____. 1966. Economics of outdoor recreation. Johns Hopkins Press, Resources for the Future. Baltimore.

CHEUNG, H. K. 1972. A day-use park visitations model. J. Leisure Res. 4:139-156.

ELLIS, J. B. and C. S. VAN DOREN. 1966. A comparative evaluation of gravity and system theory models for statewide recreational traffic flows. J. Reg. Sci. 6:57-70.

FORRESTER, J. W. 1961. Industrial dynamics. M.I.T. Press. Cambridge, Mass. 464pp.

_____. 1971. World dynamics. Wright Allen Press. Cambridge, Mass.

MUELLER, E. and GUERIN. 1962. Participation in outdoor recreation: Factors affecting demand among American adults. ORRC Study Rep. 20. Univ. Michigan Survey Res. Center. Ann Arbor, Mich.

OUTDOOR RECREATION RESOURCES REVIEW COMMISSION. 1962. Prospective demand for outdoor recreation. ORRC Study Rep. 26. Wash. D. C.

WILKINSON, P. F. 1973. The use of models in predicting the consumption of outdoor recreation. J. Leisure Res. 3:34-48.

APPENDIX I VARIABLES USED IN MODEL

SYMBOL	DEFINITION	INITIAL VALUE
APV	Alcan paved	25
DA	Distance from Anchorage	200
DLA	Demand quotient local population, age class 1	7,500
DLAI	Demand quotient local population, age class 1 absorber	-
DLAO	Demand quotient local population, age class 1 generator	-
DLB	Demand quotient local population, age class 2	40,000
DLBI	Demand quotient local population, age class 2 absorber	-
DLBO	Demand quotient local population, age class 2 generator	-
DLC	Demand quotient local population, age class 3	40,000
DLCI	Demand quotient local population, age class 3 absorber	-

DLCO	Demand quotient local population, age class 3 generator	-
DRA	Demand quotient regional population, age class 1	11,000,000
DRAI	Demand quotient regional population, age class 1 absorber	-
DRAO	Demand quotient regional population, age class 1 generator	-
DRB	Demand quotient regional population, age class 2	7,000,000
DRBI	Demand quotient regional population, age class 2 absorber	-
DRBO	Demand quotient regional population, age class 2 generator	-
DRC	Demand quotient regional population, age class 3	7,000,000
DRCI	Demand quotient regional population, age class 3 absorber	-
DRCO	Demand quotient regional population, age class 3 generator	-
EAA	Ease of access non-resident campers	calc.
EAB	Ease of access non-resident campers	calc.
EAC	Ease of access for tour group people	calc.
EAD	Ease of access backpackers	calc.
EAS	# flights to Anchorage/year	70
FAV	Fuel availability index	1.
KR	Kilometers road in park	100
KT	Kilometers trail in park	50
LOP	Level of publicity	1.
LOSA	Length of stay non-resident campers, days	6
LOSB	Length of stay resident campers	5
LOSC	Length of stay for tour group people	2
LOSD	Length of stay backpackers	10
NTRB	# of visitor trips resident campers	calc.
NTRD	# of visitor trips backpackers	calc.
PA	Park desirability cost availability	1.0
PAI	Park cost availability generator	-
PAO	Park cost availability absorber	-
TWV	Total WRSE visitor days 1 year	calc.
UC	Units campground in park	150
UL	Units lodging in park	125
VDA	Visitor days non-resident campers	calc.
VDB	Visitor days resident campers	calc.
VDC	Visitor days for tour group people	calc.
VDD	Visitor days for backpackers	calc.
WB	Visitor days backpackers	40,000
WBI	Visitor days generator backpackers	calc.
WBO	Visitor days absorber backpackers	calc.
WN	Visitor days, non-resident campers	23,000
WNI	Visitor days generator non-resident campers	calc.
WNO	Visitor days absorber non-resident campers	calc.
WO	Visitor days tour groups	34,000
WOI	Visitor days generator tour groups	calc.
WOO	Visitor days absorber tour groups	calc.
WR	Visitor days resident campers	52,000
WRI	Visitor days generator resident campers	calc.
WRO	Visitor days absorber resident campers	calc.
COL	Cost of living	1.0
PB	Park desirability for backpackers	3.0
PC	Park desirability for campers	3.0
PT	Park desirability for tour groups	2.5
PBI	Park desirability for backpackers, generator	.01
PCI	Park desirability for campers, generator	.01
PTI	Park desirability for tour groups generator	.01
PBO	Park desirability for backpackers, absorber	.01

PCO	Park desirability for campers, absorber	.01
PTO	Park desirability for tour groups, absorber	.01
UE	Unemployment index	6
	Natural Rates of Increase, Decrease	
NCOL	Cost of living	1.0
APN	Alcan paving	1.15
EAN	Flights to Anchorage	1.3
FAN	Fuel index	1.0
LON	Level of publicity	1.0
NKT	Trails/year	1.02
NKR	Roads/year	1.04
NUL	Units lodging/year	1.02
NUC	Units campground/year	1.05
NUE	Unemployment	1.0
DLAIN	Demand quotient, local population age class 1	.05
DLBIN	Demand quotient, local population age class 2	.04
DLCIN	Demand quotient, local population age class 3	.01
DRAIN	Demand quotient, Region, age class 1	.03
DRBIN	Demand quotient, Region, age class 2	.02
DRCIN	Demand quotient, Region, age class 3	.025
DLAON	Demand quotient, local age class 1	.01
DLBON	Demand quotient, local age class 2	.01
DLCON	Demand quotient, local age class 3	.01
DRAON	Demand quotient, Region, age class 1	.01
DRBON	Demand quotient, Region, age class 2	.015
DRCON	Demand quotient, Region, age class 3	.01
PAIN	Cost availability	.01
PAON	Cost availability	.01
PBIN	Park desirability, backpackers	.01
PBON	Park desirability, backpackers	.01
PCIN	Park desirability, campers	.01
PCON	Park desirability, campers	.01
PTIN	Park desirability, tour groups	.01
PTON	Park desirability, tour groups	.01
WBIN	Visitor days backpackers	.12
WBON	Visitor days backpackers	.01
WRIN	Visitor days resident campers	.10
WRON	Visitor days resident campers	.01
WNIN	Visitor days non resident campers	.10
WNON	Visitor days non resident campers	.01
WOIN	Visitor days tour groups	.07
WOON	Visitor days tour groups	.01

APPENDIX II MULTIPLIERS USED IN MODEL

SYMBOL	DEFINITION
AM	Demand quotient from % alcan paved for age 3 multiplier
APM	Demand quotient from % alcan paved for age 2 multiplier
APVM	Demand quotient region age class 1 from % alcan paved multiplier
ACOLM	Park economic availability from cost of living multiplier
VCOLM	Park economic availability from cost of living multiplier
AEAM	Demand quotient region age class 1 air access multiplier
BEAM	Demand quotient region age class 1 air access multiplier
AEASM	Demand quotient from air access for age class 3 multiplier
BEASM	Demand quotient from air access for age class 3 multiplier
AEM	Demand quotient from air access for age class 3 multiplier
BEM	Demand quotient from air access for age class 3 multiplier
AFAVM	Park economic availability from fuel index multiplier
BFAVM	Park economic availability from fuel index multiplier
LBNTM	Length of stay from # of trips for resident campers multiplier
LDNTM	Length of stay from # of trips for backpackers multiplier
LM	Demand quotient from level of publicity for age class 3 multiplier
LOM	Demand quotient from level of publicity for age class 2 multiplier
LOPM	Demand quotient region age class 1 from level of publicity multiplier
NTM	# of trips from ease of access for backpackers multiplier
NTRM	# of trips from ease of access for resident campers multiplier
APKTM	Park desirability backpackers from kilometers trails multiplier
PKTCM	Park desirability campers from kilometers trails multiplier
PKRM	Park desirability tour groups from kilometers roads multiplier
APULM	Park desirability from units lodge multiplier
BPULM	Park desirability from units lodge multiplier
PWM	Park desirability backpackers from total WRSE visitors multiplier
PCWM	Park desirability campers from total WRSE visitors multiplier
PUCM	Park desirability backpackers from units campground multiplier
AUEM	Park economic availability from unemployment publicity multiplier
BUCM	Park economic availability from unemployment publicity multiplier
AWBPM	WRSE backpackers from park desirability multiplier
BWBPM	WRSE backpackers from park desirability multiplier
AWNPM	WRSE non-resident campers from park desirability multiplier
BWNPM	WRSE non-resident campers from park desirability multiplier
AWOPM	WRSE tour groups from park desirability multiplier
BWOPM	WRSE tour groups from park desirability multiplier
AWRPM	WRSE resident campers from park desirability multiplier
BWRPM	WRSE resident campers from park desirability multiplier
APUCM	Park desirability for campers from units campground multiplier
BPUCM	Park desirability for campers from units campground multiplier
ADLPM	Demand quotient local from park economic availability for age class 1 multiplier
BDLPM	Demand quotient local from park economic availability for age class 1 multiplier

ADRPM	Demand quotient region from park economic availability for age class 1 multiplier
BDRPM	Demand quotient region from park economic availability for age class I multiplier
ADLM	Demand quotient local from park economic availability for age class 2 multiplier
BDLM	Demand quotient local from park economic availability for age class 2 multiplier
ADRM	Demand quotient region from park economic availability for age class 2 multiplier
BDRM	Demand quotient region from park economic availability for age class 2 multiplier
ARM	Demand quotient region from park economic availability for age class 3 multiplier
BRM	Demand quotient region from park economic availability for age class 3 multiplier
ALM	Demand quotient local from park economic availability for age class 3 multiplier
BLM	Demand quotient local from park economic availability for age class 3 multiplier
APKRM	Park desirability campers from roads multiplier
BPKRM	Park desirability campers from roads multiplier
APKRBM	Park desirability backpackers from roads multiplier
BPKRBM	Park desirability backpackers from roads multiplier

THE USE OF SPATIAL SIMULATION MODELS IN EVALUATING LAND-USE AND RESOURCE MANAGEMENT STRATEGIES IN THE PROPOSED ALASKAN PARKS

R. Gerald Wright[1]

INTRODUCTION

The National Park Service has in recent years found it necessary to adopt more vigorous and objective techniques for making land-use decisions. The need to expand the planning horizon has grown in part from an increased understanding of the complexity of the interrelationships in natural ecosystems, and from an environmentally aroused public. However, in a large measure, it is attributable to the ramifications spawned by the passage of NEPA in 1969 (Dickert and Domeny 1974; Parton and Wright 1976; Twiss 1974). An important ramification of NEPA has been in its demand for an environmentally sound planning process, one which provides for public input and involvement at all steps of the decision-making process (Wright 1974).

BACKGROUND

Whereas it once was possible to decide issues very quickly, based on the opinions of a select number of advisors, the decision process now demands the use of increasingly sophisticated methods providing greater objectivity and insight into the operation of natural systems and working in a minimum period of time. Figure 1 illustrates a conception of the historical changes in the time required to make land-use decisions.

Two potential alternative futures are shown, one a continued increase in the time required for decision-making, or secondly, a marked decline, based on the assumption that methodologies being developed today will succeed in making the decision-making process more efficient. This paper will address that latter viewpoint.

In an attempt to do this, one focus of the National Park Service and in fact most land management agencies has been on the use of different types of land use allocation models. The goals of most of these methods are essentially similar, although the techniques may differ. The primary objective is the identification of areas suitable for different land uses by recognizing the natural constraints of the environment (Murray et al. 1971). In this form of analysis, all information is keyed to the land resource. Typical data categories include soil type, vegetation cover, elevation, location of cultural resources, and others. Commonly, these data are categorized and displayed on maps which overlay the study area. The initial uses of these analyses were for intensive recreational site planning (campground locations, housing developments, highway corridor alignment). More recently, planning studies on large natural areas have emphasized broad recreational classifications and potential resource management strategies (Wright 1975; Craven et al. 1972).

Several large National Park Service planning studies have recently centered on land-use models. Included in these are the master plan studies for Great Smoky Mountains and Yosemite National Parks, and Delaware Water Gap NRA. Although these studies differed in their complexity and approach, the techniques were basically the same. This was to record (digitize) and computer store the spatial data according to a predetermined cell (grid) structure. One of several available computer programs was then used to examine the data, providing the options of: 1) defining only those areas where several or all data elements meet a specific set of values; 2) to equivalently define those areas where specific values are absent; 3) to combine different sets of data to look at potential land-use conflicts; and 4) to perform simple statistical analyses on different data sets.

This method provides a good system for organizing and retrieving data, both by subject matter and geographical area. The map output is easy to use and easily understood by people not familar with the process, thus important data can be visually displayed and discussed, for example, in public meetings.

There are, however, several drawbacks which prevent such methods from becoming a panacea to planner's problems that some assume they are, and therefore limit their usefulness. Chief among these is that there is no functional relationship between the data either within or between aggregated units, thus changes in the value of one data category will not affect the values of other categories. Secondly, once mapped, the data become static and have no time variant qualities. Thus properties like succession, growth and death are not incorporated into the analyses. In terms of the way natural systems operate, both are unrealistic constraints.

OBJECTIVES

The approach presented here is the outgrowth of a long term involvement focusing on ways to improve the land-use planning process and to better resource management through the use of spatial simulation models. This paper represents one phase of that study, the conceptual development of the structure of a model incorporating both spatial and dynamic characteristics with management utility.

STUDY AREA

The model is being developed for the McCarthy quadrangle, an area of 1.8 million ha in and adjacent to the 3.5 million ha proposed Wrangell-St. Elias National Park located in southcentral Alaska. The study area is reflective of the entire proposal, a wilderness of spectacular beauty, of high mountains, ice fields, glaciers, and wide braided rivers.

MODEL

Model Background

To provide some background, a model can be defined as a set of verbal or mathematical statements which describe a system. The key is that the model only describes the most important elements of the system, omitting less significant components, and thus making it simpler than the real world. Traditionally, ecosystem simulation models have focused on one homogeneous piece of land, and thus have lacked spatial dimensionality.

[1]National Park Service, Anchorage, Alaska.

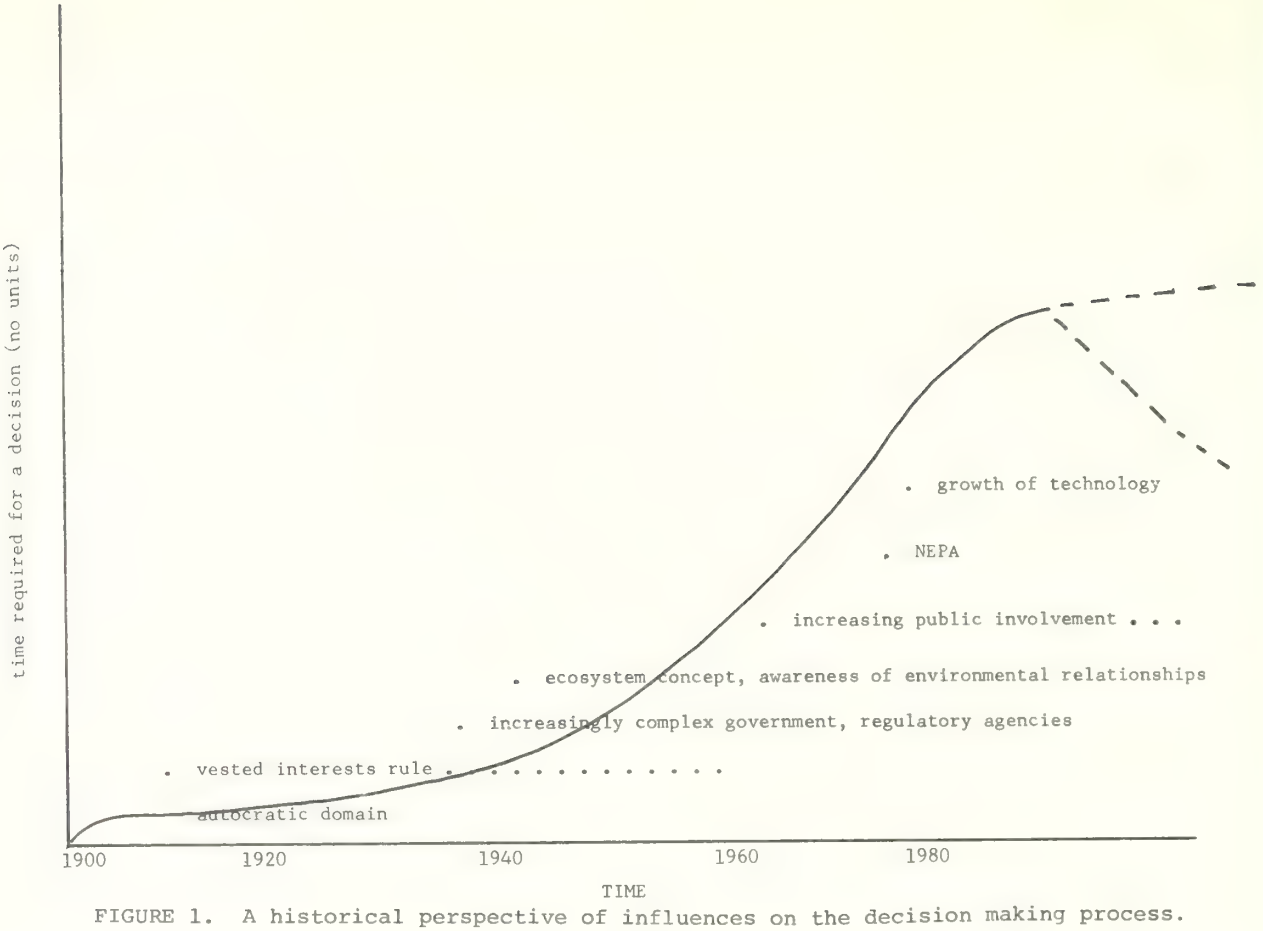

FIGURE 1. A historical perspective of influences on the decision making process.

The structure of the model described here incorporates the system dynamics concepts of Forrester (1961, 1971). Within this framework, all actions take place within feedback loops, and within these loops, the structure is based on two kinds of variables: states and flows. The states are real entities in the system that describe the condition of the system at any point in time. The rates of flow give the amount of information and energy, that accumulate or leave any state. The model has been developed using DYNAMO software.

Model Structure

Twenty two variables have been selected to describe the land system of the McCarthy quadrangle and these are listed in Table 1. They are interrelated through various feedback loops in the model.

To provide a clearer understanding of how the model will function, one set of components, the sub-model which deals with the maintenance of the sheep population is shown in Figure 2.

In this figure, the numbers of sheep in the quadrangle, a state variable is seen to be a function of the birth and death rates, which are in turn influenced by the natural long-term birth and death rates, the availability of suitable habitat, and the numbers harvested. The numbers harvested are in turn influenced by the numbers of sheep available, their age structure and sex ratio, and the number of hunters. The latter are related by a feedback loop from the number harvested, as well as other factors such as the level of the resident population and the degree of road access which are components of other sub-models.

The variables are connected through a series of dimensionaless multipliers which relate variables of different measurement units to one another. An example relationship between the number of sheep harvested and the sheep added to the population is shown in Figure 3. Note, there is a point on the graph where the number harvested has no further effect on the population numbers. Note also, that where there is no harvest, the numbers added to the population do not increase indefinitely and likewise, maximum harvest does not remove all sheep because of age and sex restrictions on harvest.

It is through the simultaneous solution of all such flows that the model operates. The solution interval for this model is one month. The basic equation describing the condition of any state in the system at any point in time is given in the following equations:

STATE time(t) = STATE time(t-1) + addition of material from other states - deletions to other states + internal growth - internal decay

It is important to note, that models stated in the above manner offer a convenient forum for discussion, because, by its very nature, the model structure asserts that the relationships chosen for inclusion are important, and those omitted are less important, and the assumptions included are explicitly stated.

Spatial Elements

Thus far, the discussion has been of an ecosystem model with no spatial properties. To

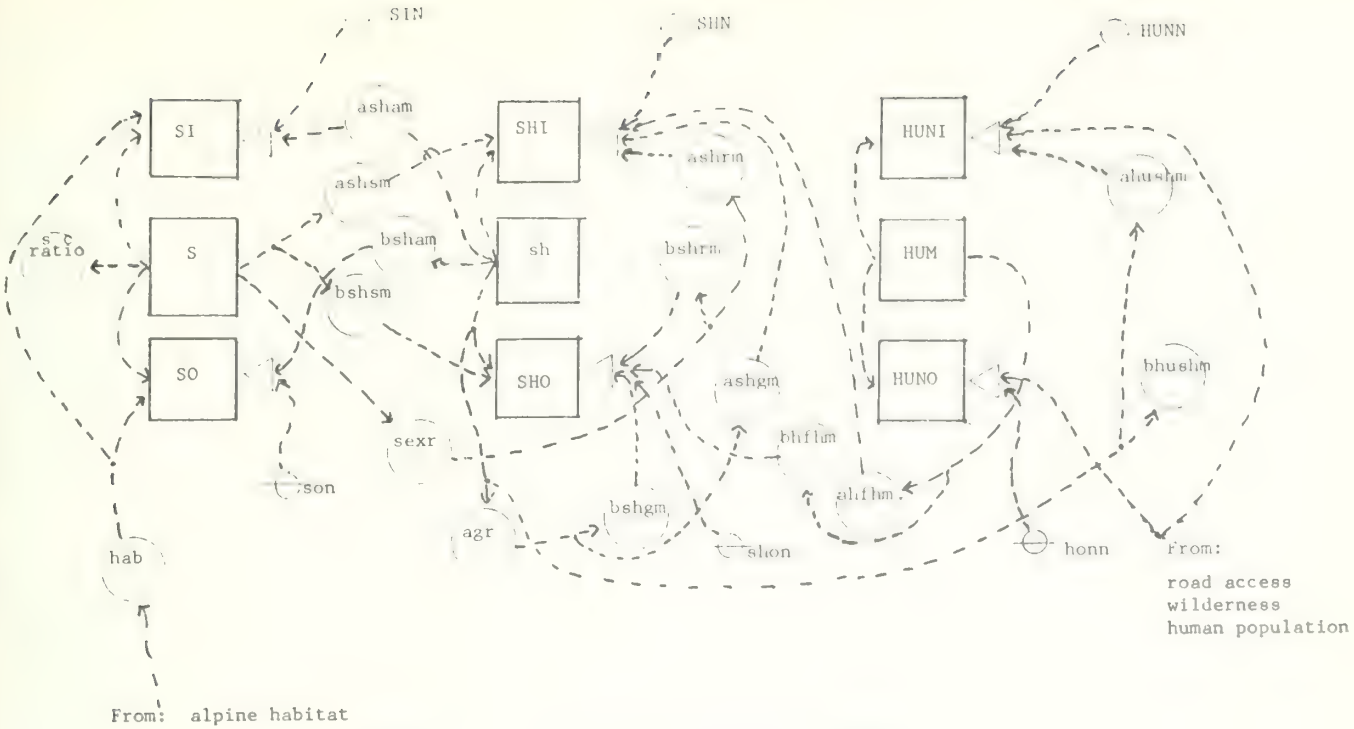

FIGURE 2. The sheep population submodel.

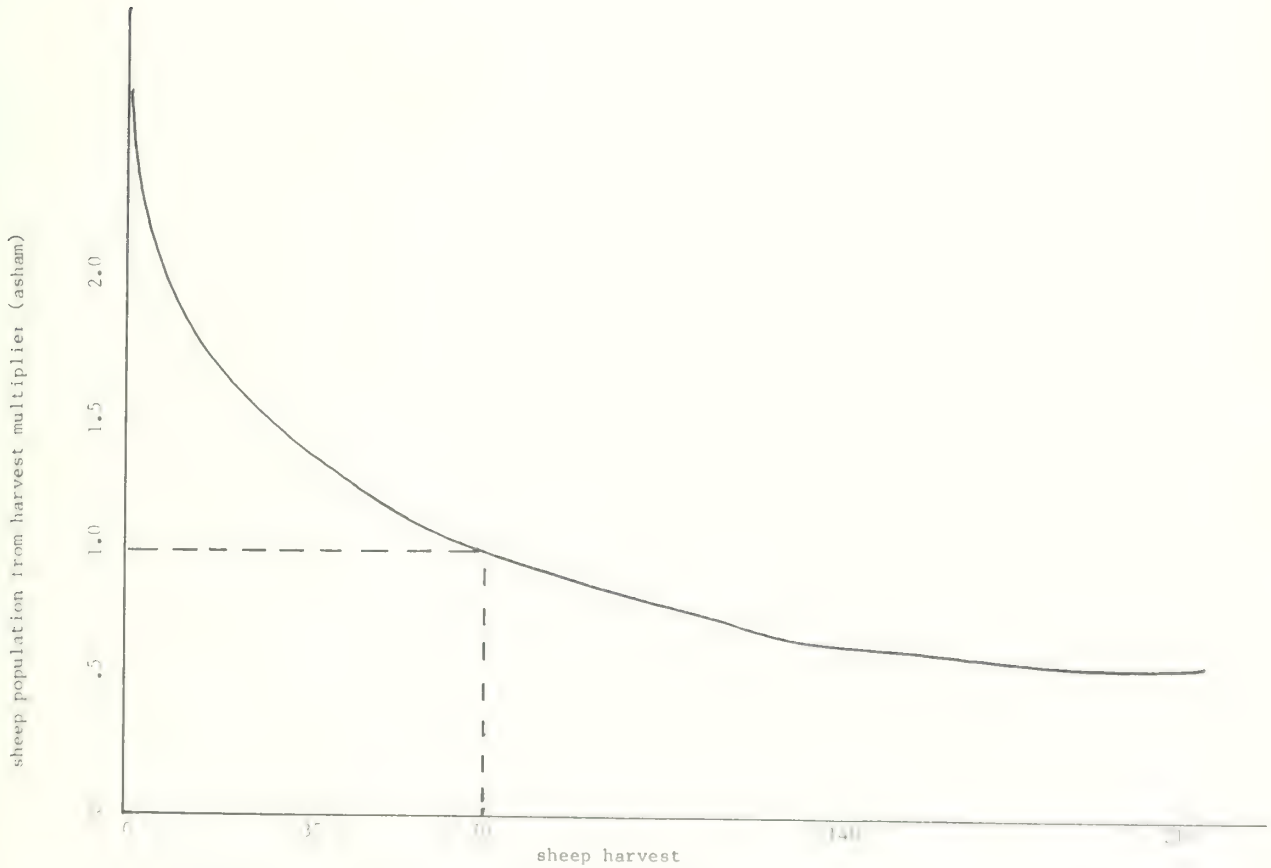

FIGURE 3. Relationship between the number of sheep harvested and the total sheep population.

TABLE 1. Primary state variables included in the model

1.	hectares black spruce
2.	black spruce harvest
3.	hectares mixed hardwoods
4.	hectares alpine tundra
5.	hectares brush land
6.	hectares marsh and bog
7.	hectares gravel moraine
8.	hectares surface water
9.	kilometers river
10.	number of moose
11.	number of moose harvested
12.	number of sheep
13.	number of sheep harvested
14.	number of wolves
15.	resident human population
16.	hectares private inholdings
17.	kilometers trail
18.	kilometers road
19.	number of hunters
20.	number of campers
21.	number of backpackers
22.	units of campground

provide for this, all of the variables have or are being spatially defined on maps of the area which are in turn digitized, and the data aggregated at the township level, although larger areas of uniform landform are considered together. There are 223 cells in the study area.

Each data aggregation is considered as a separate system and a separate simulation run is made for each. While all variables can be defined spatially, some are considered invariant (such as the location of rivers), while others have the ability to move or change in composition. Seven variables have been assumed to have dynamic spatial properties and at appropriate times in the simulation, adjustments in the elements in each cell are made based on the criteria listed in Table 2. As shown in this table, spatial adjustments are made at varying frequencies depending on the variable. Habitat conditions, and requirements, and developed access govern the cells to which dispersal is made. The computation of the simulation model for all cells with interactions is shown in the following equation which describes the condition of any state in the system for any cell, with interactions to other cells.

STATE (I,J) TIME (t)	=	STATE (I,J) TIME (t-1)	+ ADDITION OF MATERIAL FROM OTHER (I,J) STATES -
DELETIONS TO OTHER (I,J) STATES	+	INTERNAL GROWTH	- INTERNAL DECAY +
ADDITION OF MATERIAL FROM SAME STATE FROM APPROPRIATE CELLS	-	DELETION TO SAME STATE OTHER APPROPRIATE CELLS	

CONCLUSIONS

As was indicated, this study is in the development states. It has been designed both as a basis for organizing the data rapidly accumulating on the new areas in Alaska, and as a mechanism to provide greater insight and understanding of the processes at work in the areas. This will hopefully allow a better response to future questions concerning the ultimate boundaries and management policies governing the areas as well as a basis to deal with the critical resource management issues which surround the areas.

This author has submitted a formal proposal for a workshop designed to increase communication, and to work to solve some of the common problems evident in this form of analysis. It is hoped that this paper has helped in that regard.

Future work on this study calls for the model to be expanded where necessary in scope and in spatiality so as to cover the entire proposal area. At a later time, it hopefully can be adapted for use on other areas of the state.

TABLE 2. Variables dispersed among the different cells according to the listed criteria.

Variable name	Dispersal function	Dispersal time
Moose numbers	habitat quality	every month
Sheep numbers	density	every month
Bear numbers	density	months 4 through 9
Human population	quality of environment	once a year
Wolf numbers	density	every month
Number of hunters	density, hunter success	end month 8
Backpackers	density	months 6,7,8

LITERATURE CITED

CRAVEN, C. W., F. P. BAXTER, C. R. MYERS, R. J. OLSEN, V. R. SCHULLER and A. H. VOELKER. 1972. Regional environmental systems analysis. Oak Ridge National Lab. Tenn. ORNL-NSF-EP-12.

DICKERT, T. G. and K. R. DOMENY. (eds.) 1974. Environmental impact assessment: Guidelines and commentary. University Extension, Univ. Calif. Berkeley. 238pp.

FORRESTER, J. W. 1961. Industrial dynamics. M.I.T. Press. Cambridge, Mass. 464pp.

_____. 1971. World dynamics. Wright Allen Press. Cambridge, Mass.

MURRAY, T. T., T. RODGERS, D. SINTON, C. STEINITZ, R. TOTH and D. WAY. 1971. Honeyhill: A systems analysis for planning the multiple use of controlled water areas. U. S. Army Institute for Water Resources. Rep. 71-9. Volume 1 and 2. 726pp.

PARTON, W. T. and R. G. WRIGHT. 1975. The use of models in environmental impact analyses. Paper presented at symposium on Systems Analysis: Where do we go from here? Utah State Univ. Feb. 20-22, 1975. To be published in Simulation, 1976.

TWISS, R. H. 1974. Linking the E.I.S. to the planning process. pp. 5-16. In: T. Dickert and K. Domeny. (eds.) Environmental impact assessment: Guidelines and commentary. Univ. Calif. Berkeley.

WRIGHT, R. G. 1974. A method for assessing the impact of National Park Service policy decisions at Cape Hatteras National Seashore. Paper presented at AIBS Meetings, June 16-21, Tempe, Arizona.

_____. 1975. Great Smoky Mountains National Park - An exercise in coordinated regional planning. Paper presented at AIBS Meetings, Aug. 17-22, Corvallis, Oregon.

MONITORING EMERGENCE PERIODS OF THE SMALLER EUROPEAN ELM BARK BEETLE *SCOLYTUS MULTISTRIATUS* IN THE NATIONAL CAPITAL REGION, WITH MULTILURE BAITED TRAPS

James L. Sherald[1]

Dutch elm disease (DED) is a vascular wilt caused by the fungus *Ceratocystis ulmi* (Buism.) C. Moreau, which creates a dysfunction of the xylem or water-conducting tissue of the tree. No other shade tree disease has caused as much destruction and expense. Since first detected in Cleveland, Ohio, in 1930, DED has decimated thousands of street trees throughout the Northeast and Midwest. Estimates show that removals and replacements resulting from DED have cost as much as $100 million annually.

The American elm has been the dominant landscape tree throughout the urban parks of the National Capital Region (NCR). Over 2,500 large, stately elms grace the park areas and monument grounds of our Nation's capital. Dutch elm disease has been a major management problem since its first occurrence in the Washington area in 1947. A comprehensive control program has been successful in maintaining yearly losses at 1-3%.

In spite of good control, individual losses from areas such as the White House and monument grounds are often severely felt. In order to maintain a progressive, comprehensive integrated control program the Ecological Services Laboratory (ESL) of the NCR has been evaluating recent advances in therapy (Sherald 1976) and control of DED including biological control of the smaller European elm bark beetle *Scolytus multistriatus* (Marsh.), the principal DED vector in the Washington, D.C., area (Sherald and Hammerschlag 1976).

The elm bark beetle breeds in the inner bark of dying or recently dead elms. Most often, brood trees are those that are declining from DED. A single infected tree can breed thousands of spore-infested beetles. Adult beetles are lured to declining elms by a chemical attractant discharged by the host. While virgin females bore through the bark of declining trees, they emit two other attractants (pheromones) which lure additional beetles of both sexes to the brood tree. Upon mating the female constructs a vertical tunnel in the inner bark along which she deposits as many as 100 eggs in two rows. The eggs hatch in one week, forming larvae, which can overwinter. The emerging larvae tunnel literally between the bark and wood for 4-5 weeks prior to forming a pupa. Pupa develop into adults in 1-2 weeks. Adults emerge from the tree by boring small emergence holes through the bark.

In infected elms brood galleries are often infested with small fungal fruiting structures called coremia, which contain thousands of sticky *C. ulmi* spores. Spores readily adhere to the beetle as it emerges from the tree. Emerging beetles, while feeding in the twig crotches of healthy elms, introduce these spores into the xylem tissue, initiating the DED infection.

DED is a vascular wilt not readily controlled by fungicides. Control measures, therefore, have been directed toward the management of the vector. The most important and successful control measure has been sanitation which involves the rapid, thorough detection, removal and destruction of potential breeding sites. Effective sanitation must include not only cultivated elms, but also wild elms in close proximity to the cultivated stand. In conjunction with sanitation, insecticides have also been effective in further reducing beetle populations. DDT was first used in beetle control programs. However, following the publication of *Silent Spring* and the revelation of the persistent and hazardous nature of DDT, methoxychlor was introduced as a more environmentally acceptable substitute.

Although an efficient sanitation and spray program can greatly reduce the incidence of DED, more effective and environmentally sound control measures are continually being sought. Within the last few years, a great deal of progress has been made in the isolation and identification of the attractants responsible for luring beetles to breeding sites (Peacock 1973). Three compounds have been found instrumental in the attraction of breeding beetles. One of the compounds is α cubebene produced by the declining elm and responsible for the initial attraction of adult beetles. The two other attractants are 2,4-dimethy-5-ethyl-6, 8 dioxabicyclo (3.2.1) octane and 4-methyl-3-heptanol, pheromones emitted by the virgin female while boring into the trunk. The pheromones are aggregate attractants which attract both sexes. All three compounds have been artificially synthesized and combined to form the synthetic attractant multilure (Pearce et al. 1975). Traps baited with multilure can be used as a survey tool or possibly as a biological control for the elm bark beetle.

The NCR is exploring multilure trapping as a possible supplement to its current control program or as a substitute for its nonspecific insecticide applications. In 1975, the ESL participated with the USDA Northeastern Forest Experiment Station, Delaware, Ohio, in several multilure projects. The project of particular interest was a survey of the beetle emergence pattern within the urban park area of NCR.

MATERIALS AND METHODS

Survey traps were installed in 50 locations throughout the park. Traps consisted of hardware cloth (30 x 30 cm) coated with Stickem Special ® and baited with multilure dispensers. In 1975, traps were installed on April 21 and changed biweekly through October 14. Beetles were counted on each trap for the biweekly trapping period.

RESULTS

Emergence began after May 5 (Figure 1). The first emergence period, spring emergence, peaked in the first week of June with a maximum mean catch of 500 beetles per trap. A second emergence period, summer emergence, began after June 30, reaching a maximum of 1,000 beetles per trap on July 28. The emergence ratio for the spring (April 21-June 30) and summer (June 30-October 14)

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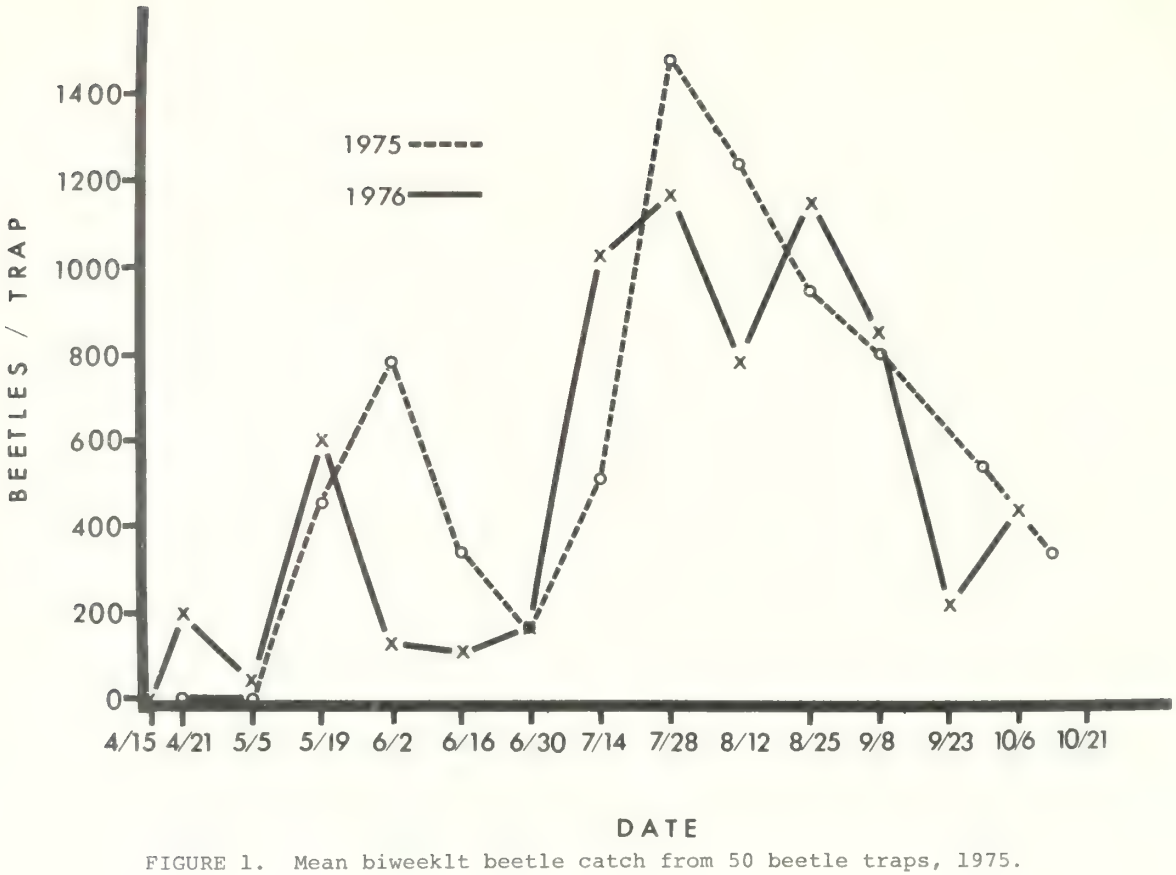

FIGURE 1. Mean biweeklt beetle catch from 50 beetle traps, 1975.

periods was 1:3.6. Seventy-eight percent of the 1975 beetle population emerged after June 30. Three traps, which remained in place after October 14, continued to trap some beetles until the first week of November.

In 1976 a smaller emergence survey was made with 11 traps installed in 11 of the locations used in 1975. The 1976 trapping period was from April 15 through October 6. Beetles were trapped immediately upon trap installation indicating that emergence began at least 3 weeks earlier than in 1975 (Figure 2). The earlier emergence may reflect the record high temperatures for the third week in April in the Washington D. C., area. Emergence briefly declined after April 21 and increased again after May 5. The spring emergence reached a maximum mean of 600 beetles per trap by May 19.

The summer emergence period began after June 16 and reached an initial peak of 1,160 beetles on July 28, followed by a second peak of 1,140 on August 25. The interruption of the summer emergence period is not understood. A possible third emergence was suggested by an increase in the beetle count on October 6, the last collection date in 1976.

The 1976 emergence ratio for the spring and summer periods was 1:3.4 compared with 1:5.3 for the same locations in 1975 (Table 1).

DISCUSSION

Many sanitation programs allow brood trees to remain standing throughout the summer emergence period, scheduling tree removals for the fall and winter. Emergence surveys in 1975 and 1976 showed

TABLE 1. Beetle emergence ratios for 1975 and 1976.[a]

Spring		Summer		Total	Ratio
Year	period	Beetles trapped	Period	Beetles trapped		Spring & Summer
1975	4/21-6/30	19,270	6/30-10/14	65,480	84,750	1:1.4
1976	4/15-6/16	12,020	6/16-10/6	63,885	75,905	1:5.3

[a]Derived from 11 survey locations.

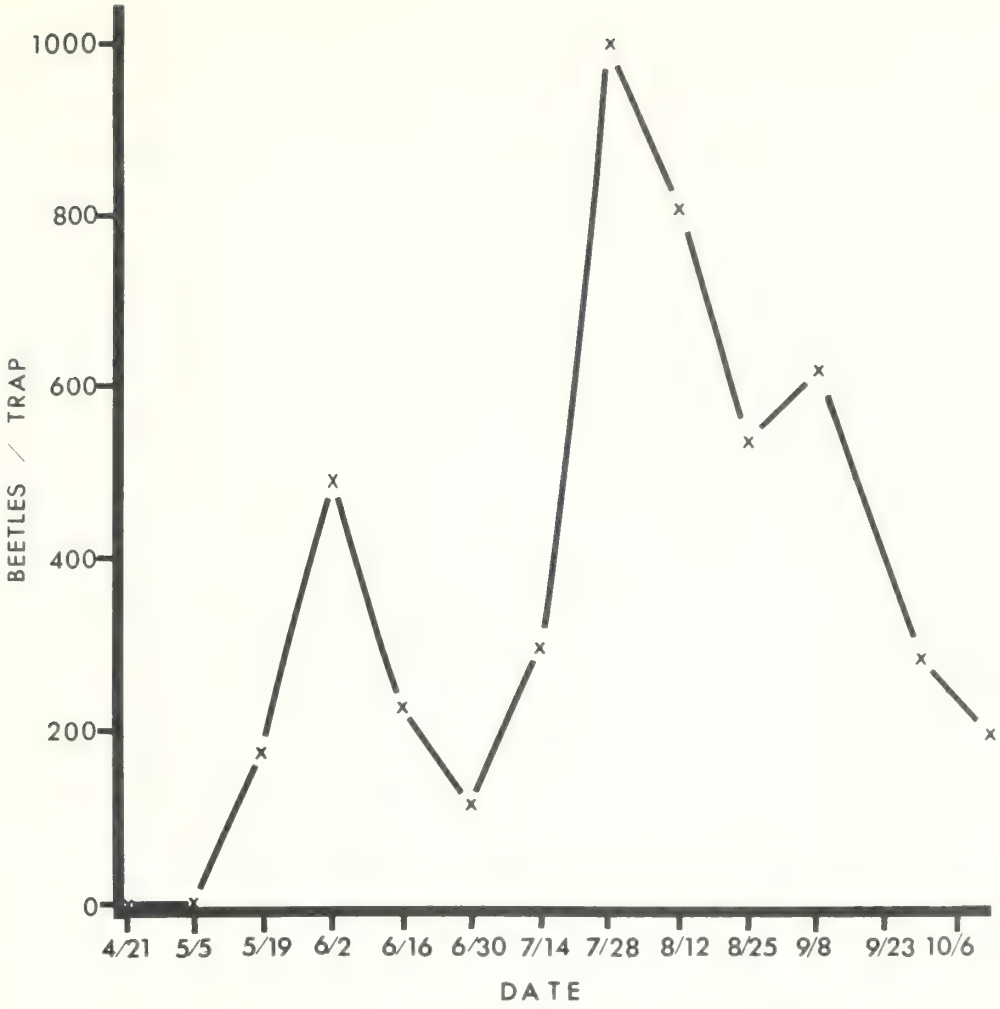

FIGURE 2. Mean biweekly beetle catch from 11 beetle traps, 1975-76.

that as much as 80% of the beetle population can emerge after June. This would suggest an advantage in removing brood wood before July to lessen the impact of the summer emerging beetles. Most trees infected with DED can be detected in the spring and early summer and could be removed before the second emergence and before such trees can serve as brood wood. Early removal is currently being practiced in NCR. Beetle monitoring may be of practical value in the timing of cover sprays. Currently, methoxychlor is applied in late winter or early spring prior to leaf expansion, to facilitate thorough coverage of twig crotches. In the NCR a cover spray is also applied in midsummer for leaf coverage. The cover spray protects against leaf feeding insects, and also provides additional treated surface for contact control of the elm bark beetle. A beetle trap survey could be used to time the cover spray for the beginning of the summer emergence period, possibly increasing insecticide control for the period when the majority of the beetles are active.

It is ultimately hoped that some mass trapping procedures can be used to eliminate enough beetles to reduce the incidence of DED. Various traps and techniques are being evaluated by entomologists at the College of Environmental Science and Forestry at Syracuse University and at the USDA Northeastern Forest Experiment Station. A technique of particular interest to the NCR is perimeter trapping which involves the installation of trap clusters around the periphery of small areas. This approach may effectively restrict the influx of beetles from outside the perimeter, as well as lure beetles from within. Perimeter trapping in conjunction with other control measures may further reduce the disease incidence within the area.

A thorough evaluation of perimeter trapping, as well as other techniques will be made before mass trapping is adopted as a routine control procedure in NCR.

LITERATURE CITED

PEACOCK, J. W. 1973. Research on chemical and biological control of elm bark beetles. Proc. I.U.F.R.O. Conf. Sept. pp. 18-53.

PEARCE, G. T., W. E. GORE, R. M. SILVERSTEIN, J. W. PEACOCK, R. A. CUTHBERT, G. N. LANIER and J. B. SIMEONE. 1975. Chemical attractants for the smaller European elm bark beetle, *Scolytus multistriatus* (Coleoptera:Scolytidae). J. Chem. Ecol. 1:115-124.

SHERALD, J. L. and R. S. HAMMERSCHLAG. 1976. How National Capital Parks control Dutch elm disease. Weeds, Trees & Turf. July. pp. 26-32.

SHERALD, J. L. 1976. Experiences with high-pressure injection of benomyl hydrochloride against Dutch elm disease. Proc. 31st Ann. Dutch Elm Disease Conf., Waltham, MA., In Press.

THE IMPACT OF DEFOLIATION BY GYPSY MOTHS ON THE FOREST AT MORRISTOWN NATIONAL HISTORIC PARK, NEW JERSEY

Joan G. Ehrenfeld[1]

INTRODUCTION

This study concerns the long-term effects of a severe gypsy moth infestation on the forest at Morristown National Historic Park, in northern New Jersey. The Park contains approximately 1150 acres of mixed hardwood forests of a variety of successional stages and edaphic types. The gypsy moth (*Porthetria dispar* L.) was first detected in the Park in 1959 (Weig 1971), and in 1960 the entire Park was sprayed with DDT. Defoliation resumed in 1966, and by 1968 moderate to heavy defoliation was noted throughout the Park. The gypsy moth population collapsed in 1970, and no significant defoliation has occurred since then.

In 1968, a survey of egg masses was conducted by the U. S. Forest Service (Ford 1968), and the Forest Service recommended that the entire forested area of the Park (the Jockey Hollow area) be sprayed with the chemical insecticide Sevin. However, the National Park Service elected to "let nature take its course," i.e., to let the moth population collapse by itself, in order to avoid the harmful environmental effects of such extensive spraying. Subsequent surveys by Park personnel (Fauber 1971) and a New Jersey Department of Agriculture entomologist (Kegg 1971) showed that approximately 10,000 oaks had succumbed to the repeated defoliation; this is, on average, 9 trees per acre. Both studies found that red and white oaks (*Quercus rubra* and *Q. alba*) fared worse than the chestnut, black and scarlet oaks (*Q. prinus, Q. velutina* and *Q. coccinea*); the total oak mortality ranged from 28% to 69%, depending on the site and the source of the estimate.

The question that remains, is what long-term effects on the forest will ensue from the defoliation and oak mortality. There is a surprising lack of information on this point, despite the large sums of money spent on this pest. For example, in the 1974 Environmental Impact Statement prepared by the U. S. Department of Agriculture (Anon. 1974a) for the gypsy moth suppression program, only seven papers are referenced on the topic of "Changes in forest stand composition," and some of these contain more speculation than data. I attempted to answer this question, at least with respect to the forests in Jockey Hollow, by studying the vegetation that had grown up around the oaks killed during the gypsy moth infestation.

METHODS

The Forest Service surveys made during the defoliation (Chansler 1969; Ford 1968) had predicted that heavy mortality would occur in small patches of 10-20 contiguous canopy trees scattered within regions of light to moderate mortality (no more than two contiguous dead dominants); my initial reconnaissance surveys confirmed this prediction. The investigation was therefore designed to evaluate the hypothesis that the size of the gap left in the canopy would significantly affect the process of gap closure in terms of the species composition of the vegetation replacing the dead oaks.

Thirty dead oak trees were sampled; they were chosen from areas throughout the Park (Figure 1). They included red, white and black oaks ranging in diameter from 10.2 inches to 31.5 inches. Trees were selected according to the following criteria: 1) they were at least 100 ft from roads, trails, and other human disturbances, 2) the main trunk was standing and had enough remaining bark to indicate the species, and 3) the tree was either a single dead tree surrounded by living canopy trees or was surrounded by at least four other dead canopy trees. The two resulting size classes of gaps are hereafter termed "small" and "large" gaps respectively.

At each dead tree, two 50 ft line transects were laid out perpendicular to each other and intersecting at the dead oak. Canopy coverage of all stems more than 30 inches high was measured along each transect, and each stem contributing cover was recorded by species and size class (seedlings, 30 inches high to 1 inch DBH; saplings, 1-4 inches DBH; lower canopy trees 4-10 inches DBH; top canopy trees, more than 10 inches DBH). Qualitative observations on the presence of herbaceous plants, vines, and any tree reproduction were made within the 50 ft diameter circle.

For each species, an Importance Value (I.V.) was computed by adding its frequency (stems belonging to the given species, as a percentage of all stems contributing cover along the transect) to its dominance (percentage of the total cover contributed by the given species). This index can range from 0-200, and gives some indication of the degree to which each species is involved in closing the gap.

Statistical analyses of the data included Student's t-test and the Wilcoxon two-sample test for continuously distributed variables, and the X^2 and G-test statistics for frequency data (Sokal and Rohlf 1969).

RESULTS

Table 1 reports the results of the analysis of the vegetation in the gaps. Little difference in the vegetation of the two sizes of gap is apparent: the number of tree stems, the total amount of foliage covering the ground, the number of species entering the gap, the relative importance of understory and canopy species, and the degree to which the gaps are filled by a single species are all statistically similar in the two kinds of gap.

Only two significant differences were found between the two size classes of gap. There is more reproduction of oak in large gaps than there is in the small gaps. Two observations may account for this finding. Firstly, the large gaps were significantly more common on low, wet sites (63% of large gaps versus 18% of small gaps; P 0.025). Secondly, Trimble (1973) has demonstrated that oak reproduction is denser on fair or poor sites than on good sites. Therefore, oak reproduction

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FIGURE 1. Map of Morristown National Historic Park, showing location of sampled gaps surrounding dead oak trees. The shaded area is that portion of the Park for which heavy defoliation was predicted by Chansler (1969).

TABLE 1. Characteristics of the vegetation in canopy gaps.

Character	Small	Large	Significance
Mean number of species	6.7 + 0.4[1]	8.0 + 0.7	NS
Mean number of stems, all species	26.6 + 1.5	31.9 + 3.0	NS
Total cover (%)	283.5 + 9.5	255.9 + 16.4	NS
Mean total I.V., understory species	101.4 + 10.0	96.1 + 14.7	NS
Mean total I.V., canopy species	97.2 + 10.2	106.3 + 15.3	NS
Mean I.V., most important species	108.0 + 7.6	95.4 + 9.9	NS
Proportion of sites, dominant species is understory	0.87	0.60	NS
Proportion of sites with any oak regeneration	0.20	0.67	P 0.05[2]
Mean % of all stems in seedling size class	10.5	16.7	P 0.025[3]

[1]Sample size = 15 for all data; standard error follows each datum.
[2]G-test for independence (Sokal and Rohlf 1969).
[3]Wilcoxon two-sample test (Sokal and Rohlf 1969).

FIGURE 2. A large canopy gap caused by the death of the three white oaks in the photographs, plus several adjacent trees. A pole-size beech tree and a sapling-size dogwood have effectively filled the gap.

associated with site quality may explain this finding.

The other significant difference between large and small gaps is the greater average proportion of stems that are in the seedling category in the large gaps. This finding may indicate that an increase in light and temperature was associated with the establishment of the large gaps and stimulated an increase in germination, sprout initiation, and seedling growth. This effect was shown by Collins (1961) in the case of red maple seedlings growing under defoliated oaks. Finally, I found no significant difference in the frequency of sapling or lower canopy-sized trees between the two kinds of gaps.

Several other features of the vegetation of the gaps should be noted. In 26% of all gaps, a lower canopy-sized tree was growing within 2 ft of the dead oak; its release, following the death of the oak, had effectively filled the gap almost immediately. Thus, these gaps had suffered no appreciable change in physical conditions on the forest floor, except perhaps during the months of defoliation preceding the release of the young replacement trees. This feature of the vegetation is illustrated in Figure 2.

Another striking feature of the vegetation was the lack of differentiation of the forest floor under most of the gaps from the floor of the surrounding intact forest. Figure 3 illustrates the typical view; the extent of the opening in the canopy cannot be determined from the vegetation on the ground. In only 25% of the large gaps (and in one of the small gaps), was the area of the gap demarked by herbaceous growth not present under the closed canopy.

The data from each gap were examined to identify the species of tree most likely to replace the oak in the canopy. Figure 4 shows the most important species of trees reproducing in the gaps; i.e., that species of tree with at least one seed-

FIGURE 3. Forest floor surrounding a dead black oak tree ('X") in a small canopy gap. The approximate limits of the opening in the canopy are shown by the arrows.

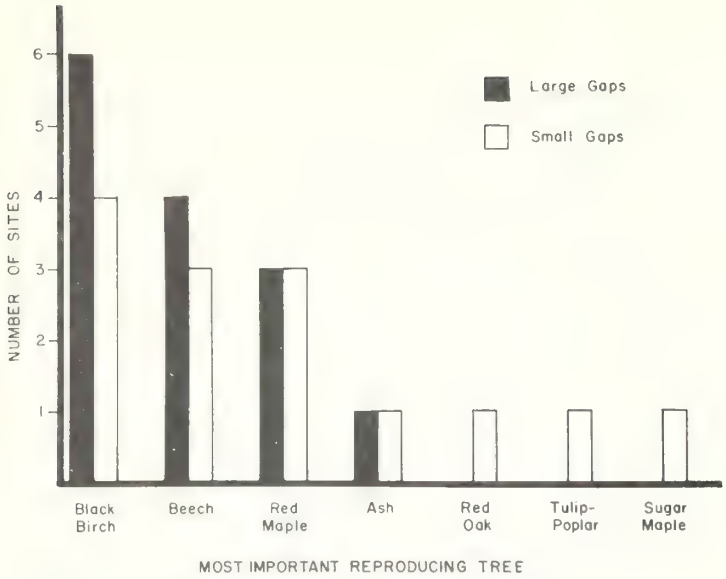

FIGURE 4. Frequency distribution of reproducing canopy trees with the highest I.V. in each gap.

ling or sapling stem, that had the highest I.V. in each gap. Again, there is no significant difference in the trees that are filling large and small gaps. In 82% of all gaps, this tree was a member of the surrounding cover type association, and not an invader foreign to the existing forest community. Thus, although oaks do not dominate the reproduction in the gaps, little change in cover type is anticipated in areas of either high or low mortality. In both types of sites, these trees were equally divided between tolerant and intolerant types; thus, the larger gaps did not particularly favor the establishment of intolerant species. As with the other aspects of gap vegetation discussed above, the pre-existing forest and surrounding community composition determined the species that closed the gaps; where red maple was abundant in all forest strata, it took over the gap, but where sugar maple or beach dominated the area, these highly tolerant, late successional species filled the gap.

However, the I.V. calculations showed that at two-thirds of all sites, the most important species belonged to the understory and shrub layers; these plants were principally *Cornus florida* and *Lindera benzoin*. The dense presence of these species in the community immediately surrounding these gaps, and their paucity around the remaining gaps, impressed the observer strongly. Thus, where the shrub layer was well developed, it closed the gap, and where it was absent or sparse, tree reproduction closed the gap. For example, at one large gap in an area of sparse *Viburnum acerifolium*, 66% of the stems covering the line transects belonged to tree species. At another large gap, in an extensive area of dense *L. benzoin* cover, 59% of the stems were *Lindera* alone, and another 14% belonged to *C. florida* and *Hamamelis virginiana*. Again, if dogwood has an important understory tree in the surrounding stand, it expanded to fill the gap by growing horizontally toward the light, and sending up many vertical shoots. For example, at one large gap, dogwood supplied 86% of the stems and 84% of the cover, and two-thirds of the dogwoods were more than 4 inches DBH.

DISCUSSION AND CONCLUSIONS

Three factors can be identified from this study that are important to the process of forest recovery after mortality from gypsy moth defoliation. First, and least important, is the role of chance; examples might be the location of a young tree, adjacent to the dead tree, which can immediately close the gap, or the random effects of falling branches and pieces of trunk in destroying existing advance reproduction. Second, the process of natural succession has affected the composition of the advance reproduction that was established before the death of the oaks. Thus, in places in which oak is evidently giving way to a beech-maple-birch association, the gypsy moth is simply hastening the departure of the oak seral stage and promoting the arrival of the putative climax community, and in areas in which the oak-dominated commmunity is reproducing successfully, the gypsy moth is releasing the regeneration of oak and its associates (mainly black birch), and favoring this intermediate seral stage. Third, and most important, the composition of the immediately surrounding community determines the major features of the gap vegetation--the relative importance of shrubs or understory species, the species of tree most likely to replace the dead tree, the density of the vegetation. These results are similar to those Monk (1961) described for windthrow gaps in another oak forest in New Jersey.

In the size range studied here (one to twenty contiguous dead canopy trees), gap size is not an important variable. That is, there is no evidence that gaps created by the death of adjacent dominant trees provided a habitat for pioneer species. It is, of course, entirely possible that gaps an order of magnitude larger might well exert a different effect.

Two long-term effects of the gypsy moth on the forest at Jockey Hollow are apparent. First, the growth of dense stands of shrub and understory species has been reinforced in places where this is already a prominent feature of the vegetation. Second, there has been a reduction in the proportional representation of oaks among the dominant and codominant trees, and although this change is likely to be long-lasting, no change in the cover type associations is expected.

The rejection of chemical control methods for the gypsy moth incurred the wrath of many local citizens and other residents of New Jersey. Fears were expressed that the infestation would spread ruin over adjoining private property and that the forests at Jockey Hollow would be destroyed. It was also argued that the presence of the moth and the sight of dead trees seriously impaired the "recreation value" of the Park, and themselves justified chemical control measures (Kegg 1971). However, the moth larvae are present for only three months of the year (Campbell 1974), and many of the dead trees are not within sight of the trails, and thus their impact on Park visitors is small. In addition, forest recreation is secondary in importance to the appreciation and understanding of the historical events for which the Park was established. Finally, it is apparent from this study that no major change in community composition directly attributable to the moth is predicated for either highly defoliated or moderately defoliated parts of the forest. In particular, nowhere are early successional species of woody or non-woody plants invading the gaps. Thus, the National Park Service was wholly justified in its management decision not to blanket the Park with chemical insecticide.

On the basis of these results, I offer the following recommendation for managing future problems from insect defoliation in National Parks: where there is a question of damage to unusual scenic, historic or ecological forest resources, surveys conducted at the time of the infestation can be made more useful by including

data on 1) the size of the patches of heavy defoliation or insect damage, 2) the structure of the surrounding community, with attention paid to all forest strata, and 3) the drainage and site quality characteristics of the threatened area. When combined with defoliation and/or mortality predictions, these data would permit management decisions to be made on a selective basis for relatively small areas, rather than on an all-or-nothing basis for large areas. In view of the availability of mechanical control techniques (Nichols 1973), biological control methods and sprays (Anon. 1974a), and parasite introduction programs (Anon. 1974b), a policy of selective control measures for small areas would be entirely feasible, both for the gypsy moth and many other pest species.

LITERATURE CITED

ANON. 1974a. Final environmental statement: cooperative gypsy moth suppression and regulatory program, 1974 activities. U.S.D.A. For. Serv. and A.P.H.I.S. 177 pp.

ANON. 1974b. 1973-1974 Annual Report, Bureau of Plant Laboratory, Division of Plant Industry, New Jersey Dept. Agric. pp. PI-63-PI-103.

CAMPBELL, R. W. 1974. The gypsy moth and its natural enemies. U.S.D.A. For. Serv. Agric. Info. Bull. Bo. 381. 27 pp.

CHANSLER, J. F. 1969. Evaluation of gypsy moth at the Morristown National Historic Park. U.S.D.A. For. Serv. unpubl. doc. on file at M.N.H.P.

COLLINS, S. 1961. Benefits to understory from canopy defoliation by gypsy moth larvae. Ecology 42:836-838.

FAUBER, R. 1971. Summary of effects of gypsy moth outbreak in Jockey Hollow. unpubl. ms. on file at M.N.H.P.

FORD, R. P. 1968. Biological evaluation of gypsy moth on the Morristown National Historic Park. U.S.D.A. For. Serv. Doc. 68-AFO-5, unpubl. ms. on file at M.N.H.P.

KEGG, J. D. 1971. The impact of gypsy moth: repeated defoliation of oak in New Jersey. Jour. Forest. 69:852-854.

MONK. C. D. 1961. The vegetation of the William L. Hutcheson Memorial Forest. N.J. Bull. Torrey Botan. Club 88:156-166.

NICHOLS, J. O. 1973. The gypsy moth. Dep. Environ. Res. Common. Pa., Bur. Forest. 16 pp.

SOKAL, R. R. and F. JAMES ROHLF. 1969. Biometry. W. H. Freeman and Co., San Francisco. 766 pp.

TRIMBLE, G. R. JR. 1973. The regeneration of central Appalachian hardwoods with emphasis on the effects of site quality and harvesting practice. U.S.D.A. For. Serv. Res. Paper NE-282. 14 pp.

WEIG, M. 1971. The 1971 gypsy moth situation in New Jersey. North Jersey Conservation Foundation, Morristown, New Jersey.

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DUTCH ELM DISEASE THERAPY IN THE NATIONAL CAPITAL PARKS--A PROGRESS REPORT

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This paper will appear in the Proceedings of the 31st Annual Dutch Elm Disease Conference, Waltham, Massachusetts, 1976, under the title "Experiences with high-pressure injection of benomyl hydrochloride against Dutch elm disease, by James L. Sherald and Warren E. Beers.

COMPARATIVE STUDIES ON GROWTH AND DEVELOPMENT OF ST. AUGUSTINE GRASS TURF AS AFFECTED BY COMMERCIALLY AVAILABLE RETARDANTS[1]

G. S. Rai[2], M. S. Ogra[2], L. Y. Yatsu[3] and J. D. Tallant[4]

INTRODUCTION

In the last two decades lawn management has assumed a special importance for the National Park Service since they provide for recreational facilities for the public at large. It is only natural that the up-keep cost for the establishment, which usually includes large areas under turfgrass, be kept within reasonable limits. This appears to be an impossible task without the use of chemical retardants , approved by EPA Standards.

Already some of these growth inhibiting substances are used on a commercial scale for specific purposes, for example, increasing flower production in camellias and azaleas (Gill and Stuart 1961; Stuart 1962). Other uses call for their applications in maintaining the size and shape of the ornamentals and trees (Hamner and Rai 1958; Rai and Hamner 1953, 1955). Yet some of the same chemicals inhibit sprouting of onions and potatoes in storage at room temperatures. To sum it up, these economic gains have revolutionized the entire crop production ventures.

Interestingly enough the application of the grass retardants has been limited to unattended grassy areas where lawn appearance was not an issue. Side phytotoxic effects apparently limit the possibilities of their practical use on well kept lawns (Foote and Himmelman 1971; Harris et al. 1971; Zukel 1957).

The success in grass retardation studies no where matches the growth manipulation achieved for dicots. It may be partly due to: (1) pattern of grass growth, (2) absorption of the chemical(s) through foliage in foliar sprays, (3) Transport of the chemical within the plant system, (4) ultimate fate of the chemical used, (5) cellular metabolic activity, (6) molecular configuration of the chemical.

According to Sachs and Mock (1975) literature provides much evidence for the experiments geared to structure/activity studies for growth retardants but no researcher seems to have explored all the six components at one time. It is obvious that any development of an ideal retardant in arresting the growth of grass must take into account the relative role of each factor in relation to prevailing environmental conditions.

Having established an idea, through visual observations to their relative performance as grass retardants on predominantly Bermuda grass plots on the campus, the experiment was shifted to turfgrass, not homogeneously St. Augustine, at Chalmette Historical Park.

The purpose of the research was to determine if differences in growth retarding activity could be accounted for in terms of structure/activity study relative to the concentrations used.

REVIEW OF LITERATURE

Several investigators have reported on the effectiveness of a number of retardants on highway roadbanks or similar areas (Cabber and Horn 1963; Chamberlin 1963; Foote and Himmelman 1971; Sachs et al. 1970; Trask et al. 1962; White et al. 1976). In addition, data have also been presented on the suppression of seedhead formation which gives unsightly appearance to turfgrasses (Anderson 1963; Cabber and Horn 1963; Chamberlin 1963; Crafts et al. 1958; Naylor and Davis 1950).

Other studies during this time were aimed at understanding the range of activity of growth retardants among species. Comparison of the activity of four analogs of Amo-1618 (4-hydroxy-5-isopropyl-2-methyl phenyl) trimethylammonium chloride, 1-piperidine carboxylate) on gibberellin production by the fungus *Fusarium moniliforme* L. and stem elongation in pinto beans (*Phaseolus vulgaris* L.), sunflower (*Helianthus annua* L.), and Japanese morning glory (*Pharbitis nil* Chois cv. Violet) indicated marked differences among analogs, dependent in part on the species treated (ZeeVaart and Osborne 1965). ZeeVaart and Osborne (1965) observed that the enzyme system involved in gibberellin bisynthesis differed in the four species to make them more or less sensitive to the analogs. However, they did not present data to substantiate this hypothesis; it is possible that a significant portion of the differences in activity measured among analogs and species may have been accounted for by differences in (1) leaf absorption, (2) transport mechanisms, (3) metabolic degradation, (4) inactivation through the formation of chemical complexes and/or (5) storage of the retardants at inactive sites. Moore (1968) also suggested that differential activity of daminozide (succinic acid 2,2,dimethyl hydrazide, SADH) plant species is probably correlated with differences in metabolic systems sensitive to SADH among the species. He presented data that eliminate accounted for differences in observed inhibition of stem elongation, but did not deal with storage at inactive sites.

MATERIALS AND METHODS

In recognizing the time limit, only 90 days, the experimental plots were set up well ahead of the spraying time which was July 17 and 18, 1975. Furthermore, to minimize the soil heterogeneity factor, due to gentle slope, Latin Square System was preferred over randomize block layout. The plot size was 15.0 feet x 11.0 feet and subplots from which the grass clippings were weighed had dimensions of 10.0 feet x 6.0 feet.

Four growth retardants were used for the trials in concentrations of 0, 1000, 5,000 and 10,000

[1]Thanks are due to Mr. Lionel Bienbenue, Superintendent of Chalmette National Historical Park, and his staff in the execution of this project during 1974 and 1975. Thanks are also due to two AFNA Students, Mr. Claude Flot and Orville Frazier, who worked on this project.

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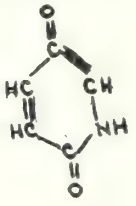
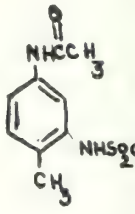
ppm., on the basis of active ingredients in aqueous solution. The maleic hydrozide (MH) supplied by the Uniroyal and Ansul Companies was regarded as two different compounds because of the unique preparation procedures of each concern. All the relevant information regarding the retardants used is given in Table 1.

Many examples of this regulatory system can be found in seeds of various kinds. Making use of this natural, yet widespread plant growth retardant mechanism, chemists have synthesized compounds which could be useful in this direction. However, few have proved trial worthy in arresting grass growth.

TABLE 1. Retardants used in the experiment at Chalmette Historical Park during the year 1974 and 1975 on turfgrass (predominantly St. Augustine).

Common name or trade name	Source	Scientific name	Active and inert ingredients	Molecular configuratio
1. Maleic hydrazide (MH)	Uniroyal Chemical Co. Haugatuck, Conn. 06770	1, 2-dihydro-3,6-pyridazine-dione	Diethanolamine Salt of 6-hydroxy-3-(2H) pyridazinone————58% INERT————42% Contains 3 pound/gallon	
2. Maleic hydrozide (MH)	Ansul Co. Marinette, Wis. 54143	Same as above	Same as above	
RETARD				
3. Maintain CF-125	U.S. Borax and Chemical Corp. 3075 Wilshire Blvd. Los Angeles, Calf. 90010	ACTIVE INGREDIENTS: Methyl 2-chloro-9hydroxy-fluorene-9-carboxylate————8.8% Methyl 9-hydroxyfluorene-9 carboxylate2.1% Methyl 2,7 dichloro-9-hydroxyfluorene-1.6% INERT INGREDIENTS————87.5% Contains 1.0 pound per gallon active ingredients.		
4. Sustar 2-5	3 M Co.	N-4-methyl-3- [(1.1,10trifluoromethyl) sulfony] amino] phenyl] acetamide Diethanolamine Salt of N- [4-methyl-3 [(1,1,1-trifluoromethyl) sulfonyl] amino] phenyl] acetamide* 30% Inert Ingredients: 70% *Equivalent to 2.0 pounds per gallon 100%		

When the spray program was initiated, July 17-18, 1975, the turfgrass plots were mowed to a uniform height of 7 inches. The amount of retardants for each treatment used was based upon the content of active ingredients. For example, for the 1000 ppm solution the calculated amount for MH was 1.724 ml/liter and correspondingly this figure was revised to 6.896 ml/4 liters. Similarly the amounts of other retardants were calculated for each treatment. The freshly prepared solution of 4 liters for each treatment was sprayed evenly with a knap sack sprayer at a uniform pressure of 10 lb/sq. inch.

The cultural treatment consisted mainly in keeping plots weed free throughout the duration of the experiment. This phase of the program proved to be very essential as the turfgrass plots were heterogeneously St. Augustine. Failure to recognize the lack of purity of the stand gave conflicting results in 1974. Therefore, the experiment was repeated in 1975. The plots were mowed after 70 days from the date of application of the retardants at a uniform height of 7 inches. The fresh and dry weight of clippings in grams from each 6.0 feet x 10.0 feet plot is recorded in Tables 2 and 3.

DISCUSSION

Growth and development is a complex problem. Equally intricate is the growth retardation phenomenon. It is widespread in nature as dormancy.

The problem lies with the peculiar nature of grass growth mechanisms. For example, meristematic zones are located close to the soil surface beyond the reach of machines. Even if some meristems are removed by defoliation, they may readily be replaced by the appearance of new tillers. Few other plants have such an efficient mechanism of growth recovery.

The stem apex (short apex, apical meristem, growing point) of each tiller occurs just above the highest node, its actual position is at the base of the tiller. Careful removal of successiv leaves reveals in the very center the apical dome an intensely meristematic region. It is along two opposite flanks of this dome that new leaves are laid down in alternating order. Formation of a leaf primordium begins by rapid cell division in the outermost cell layers of the dome, the dermatogen, and hypodermis, giving rise to a microscopically visible protuberance.

The whole leaf primordium is meristematic at its inception, but soon cell divisions become confined to an intercalary meristem at its base. Meristematic activity in the lamina comes to an end when the ligule is differentiated, but then the sheath elongates through division and enlargement of its cells, and this continues until the ligule is exposed. This marks the end of elongation growth and the foliar organ has now reached its final length. Of course, the next leaf is meanwhile moving up the previous sheath.

TABLE 2. The fresh weight in grams of clippings of St. Augustine grass when mowed to a uniform height of 7 inches 70 days after the treatments.

	CONCENTRATION PPM															
	0				1000				5,000				10,000			
CHEMICALS	R1	R2	R3	R4	R1	R2	R3	R4	R1	R2	R3	R4	R1	R2	R3	R4
MH——Uniroyal	905	1000	900	974	816	907	796	820	510	608	555	490	369	305	425	413
MH——Ansul	1142	1190	1026	1078	985	1071	894	1007	560	601	717	726	273	205	323	299
Maintain CF - 125	1011	1091	1125	962	1717	1808	1688	1801	620	711	595	635	411	427	380	466
Sustar 2-5	1044	1172	978	1043	800	870	845	795	619	590	617	632	228	191	290	274

TABLE 3. The dry weight in grams of clippings of St. Augustine grass when mowed to a uniform height of 7 inches 70 days after the treatments.

	CONCENTRATION PPM															
	0				1000				5,000				10,000			
CHEMICALS	R1	R2	R3	R4	R1	R2	R3	R4	R1	R2	R3	R4	R1	R2	R3	R4
MH——Uniroyal	252	301	273	269	260	252	221	207	137	195	154	152	107	92	136	122
MH——Ansul	289	361	334	324	265	325	291	305	212	162	258	208	82	60	96	91
Maintain CF - 125	304	328	293	269	457	589	508	587	172	202	172	196	131	126	92	137
Sustar 2-5	281	315	319	301	236	233	284	201	186	171	210	199	65	61	81	75

Comparatively little research has been done concerning factors influencing the rate of leaf initiation, presumably because it is merely the prelude to the more obvious leaf appearance. However, understanding the growth mechanisms has led to use of growth regulators in selective weed control of broad leaved annuals and perennial weeds in cereal crops. By contrast, there are chemicals which regulate the growth of grasses without damaging other plants. A good example of this action is the growth retardant CCC (2-chloroethyl) trimethylamimonium chloride, which reduces stem height in wheat and may thus lead to a greater proportion of grain to straw yield (9).

In the experiment reported herein, analysis of variance, Table 4, indicates that there was no significant difference among the four larger plots considered as blocks or replications for discussion purposes at the 95% level. Thus, it is obvious that there were fairly uniform fertility levels in all the blocks.

Table 5 represents the analysis of variance for the treatments only. The analysis showed the effect of two primary variables, rates of applications in ppm and the chemicals used. Also shown is the effect of interaction. All three causes of variation were extremely significant, that is, the rate of applications and the chemicals were different among themselves and the

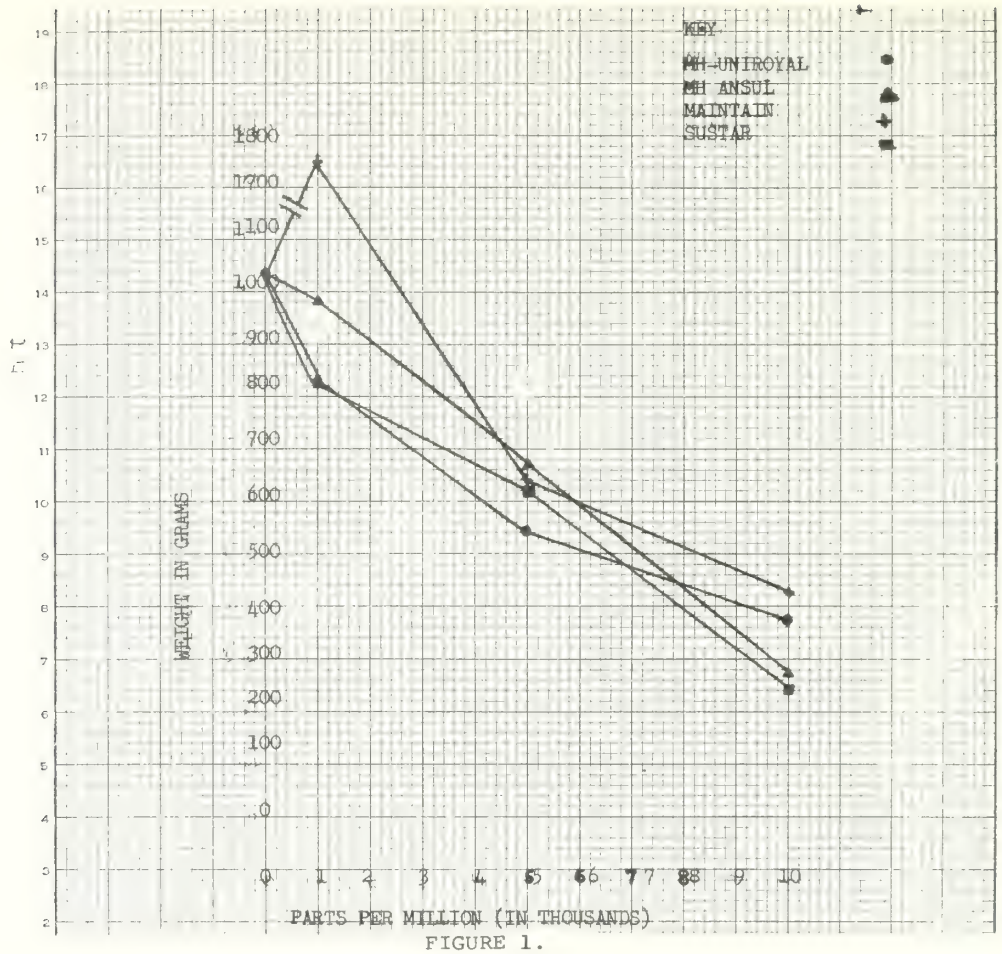


FIGURE 1.

interaction significance can be interpreted as showing that all the chemicals did not affect the grass retardation to the same degree as the rate of application was increased.

Figure 1 shows the weight of the clippings as plotted against the rate of application for each of the four chemicals. It will be noted that the slopes for each chemical are not the same. There is a difference among slopes which is measured by the above-discussed interaction.

Appearance of the turf is also very important. Therefore, each of the plots were evaluated subjectively on a 1 to 10 scale. Acceptable appearance was felt to require grades of 6 and above. All of the plots were so graded with the exception of the Maintain CF 125 at a rate of 10,000 ppm.

Figure 2 indicates the average relative weights of fresh grass clippings for all the treatments. It may be noted that the concentration of 1000 ppm almost did not arrest the grass growth. On the other hand, Maintain at this low concentration accelerated the growth processes of grass to the point of being totally ineffective in suppressing growth. Still higher concentration of Maintain 10,000 ppm had a phytotoxic effect on grass with the result that the vegetative character of the plots changed in favor of broad leaved weeds, *Erigeron* sp. and *Trifolium procumbens*. While other compounds at high concentration did not exhibit phytotoxicity beyond yellowing the leaves at random places in a plot.

For all the data, 64 observations in Table 3, the dry weight is related to the wet weight quite well by a linear equation in the following manner:

$$Y = -3.8 + .30X$$

where Y = dry weight

X = wet weight

The above simple expression has a standard error of Y of 21.4 indicating for these data that the wet weight can adequately predict the dry weight.

It is therefore concluded that an application rate of 1000 ppm is marginally effective; or in the case of Maintain CF 125 it actually enhanced growth. On the other hand, a rate of 10,000 ppm may lead to poor appearance as with Maintain and Ansul MH, but a rate 5,000 ppm seems optimum for inhibiting growth while presenting acceptable appearance.

TABLE 4. Analysis of variance of 16 control plots 4 to an area of each block of replication, fresh yield data from grass plots mowed at uniform height of 7 inches after 70 days of the first mowing operation.

Treatments	D.F.	Sum of squares	M.S.	F value
Blacks	3	56725	18917	3.4
Error	12	66452	5538	

TABLE 5. Analysis of variance of treated plots for chemicals, rate of application in ppm (1000, 5,000, and 10,000 applied July 17-18, 1975). Fresh weight yield data from grass plots mowed at uniform height of 7 inches after 70 days. The interaction among the rates and chemicals included.

Treatments	D.F.	Sum of squares	M.S.	F value
Rates	2	4.89×10^6	2.43×10^6	925.0
Chemicals	3	1.07×10^6	$.358 \times 10^6$	136.0
Rates X chem.	6	1.36×10^6	$.231 \times 10^6$	88.0
Error	36	$.944 \times 10^6$	2623.0	

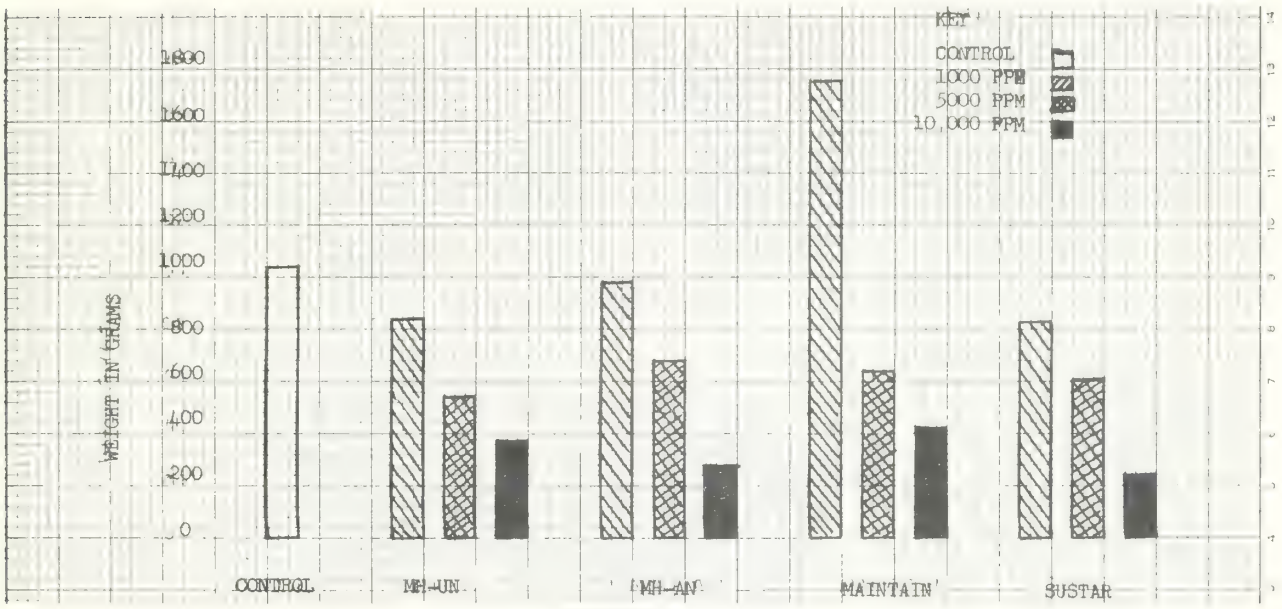


FIGURE 2.

LITERATURE CITED

ANDERSON, R. C. 1963. Inhibitors for economic maintenance. Ohio State Univ. Short course Roadside Develop. 22:74-75.

CABBER, J. F. and G. C. HORN. 1963. Chemical growth retardants for turfgrasses. Golf Course Rep. 31(1):35-44.

CHAMBERLIN, R. E. 1963. Inhibitors for roadside maintenance. Ohio State Univ. Short course Roadside Develop. 22:77.

CRAFTS, A. S., H. B. CURRIER and H. R. DREVER. 1958. Some studies on the herbicided properties of malic hydrazide. Hilgardia 27(22): 723-757.

FOOTE, L. E. and B. F. HIMMELMAN. 1971. MH as a roadside grass retardant. Weed Sci. 19:86-90.

GILL, D. L. and N. W. STUART. 1961. Stimulation of camellia flower bud initiation by application of two growth retardants - a preliminary report. Amer. Camellia year. b.p. 129-135.

HAMNER, C. L. and G. S. RAI. 1958. Maleic hydrazide and growth inhibition studies with ornamental and shade trees. Hormolog. vol. 2, 11-13.

HARRIS, G. K., G. B. FARRETTE and D. O. ANDERSON 1971. Maintain Success Boosting. Weeds, trees and turf 10:20-24.

HUMPRIES, E. C. 1968. The beneficial effect of CCC on wheat yield in dry conditions. Euphytica Suppl. 1:275-279.

MOORE, T. C. 1968. Translocation of growth retardant N,N dimethylamino-succinamic acid - ^{14}C(B-995-^{14}C). Bot. Gaz. 129:280-285.

NAYLOR, A. W. and E. A. DAVIS. 1950. Maleic hydrazide as a plant growth inhibitor. Bot. Gaz. 112:126.

RAI, G. S. and C. L. HAMNER. 1953. Plant hormones. Indian Farming. Vol. 111, No. 5, 16-18 and 32.

_____. 1955. Inhibiting the growth of plants with maleic hydrazide. Quart. Bull. Mich. Agr. Exp. Sta., vol. 37:375-386.

SACHS, R. M., W. P. HACKETT, R. G. MAIRE, T. M. KRETCHUM and J. DEBIE. 1970. Chemical control of plant growth in landscapes. Calif. Agr. Exp. Sta. Bull. 844. 20 p.

SACHS, R. M. and T. MOCK. 1975. Growth retarding activity of foliar applied daminozide (SADH) in relation to its concentration in three species. Jr. Am. Soc. Hort. Sc.: Vol. 100, No. 3, 210-212.

STUART, N. W. 1962. Azalea growth rate regulated by chemicals. Florists Rev. 194:35-36.

TRASK, A. D., P. W. BOHNE and B. S. MORGAN. 1962. Inhibitors for economic maintenance. Ohio State Univ. Short course Roadside Develop. 21:98-101.

WHITE, D. B., D. HENG, T. B. BAILEY and L. FOOTE. 1976. Chemical regulation of growth in turfgrasses. 1st Int. Turf. Conf., Proc. (Harrogate, England).

ZEEVAART, J. A. D. and H. D. OSBORNE. 1965. Comparative effects of some Amo-1718 analogs on gibberellin production in *Fusarium moniliforme* and on growth in higher plants. Planta 66:320-330.

ZUKEL, J. W. 1957. A literature summary of maleic hydrazide. Uniroyal, Inc., Naugatuck, Conn.

ROOT DISEASE, HAZARD, AND FOREST PROTECTION IN YOSEMITE VALLEY

J. R. Parmeter, Jr.[1], M. Srago[2], N. J. MacGregor[2] and F. W. Cobb, Jr.[1]

INTRODUCTION

At the time of discovery by white explorers, Yosemite Valley, under the management of the Miwok Indians, was covered mainly with meadows and open oak woodlands (Gibbens and Heady 1964). The institution of fire control and grazing in the mid-1800's led to the establishment of dense stands of ponderosa pine, incense-cedar, and lesser amounts of white fir, Douglas-fir, and other species. These stands are now about 100 years old, overstocked, and of generally poor vigor. Such conditions are conducive to root diseases.

Fomes annosus is a root-disease fungus closely related to common wood-decay fungi. It spreads by spores produced on "conks" in old stumps and snags or under the bark of dead trees. These windborne spores land on and colonize surfaces of freshly cut stumps or wounds. Once established, the fungus grows through the wood, causing decay and, in pines, death of the cambium (Bega 1963). Where roots of infected stumps of trees touch the roots of susceptible trees, the fungus grows from the infected root to the healthy root. Thus, once root systems become infected, the fungus can spread from tree-to-tree in enlarging "centers" until root-to-root spread is interrupted by nonsusceptible trees or by treeless barriers such as meadows, streams, or rock outcrops.

Fomes annosus remains alive in colonized root systems for many years. Until the fungus dies out in these old roots, young susceptible trees that become established in *F. annosus* centers are liable to infection when their roots contact the old root systems. A wide range of woody hosts can be attacked by *F. annosus*; therefore reforestation of disease centers may be difficult. Generally, hardwoods are much less susceptible than are conifers and may replace them in disease centers.

Fomes annosus was reported in Yosemite Valley by Forest Service pathologists in the 1960's. By 1971, it became apparent that the disease was widespread in the Valley. Therefore, an evaluation of the disease was undertaken jointly by the Park Service, Region 5 of the Forest Service, and the University of California at Berkeley. The objectives were: (1) to determine the number and size of *F. annosus* centers within developed areas of the Valley; (2) to estimate rates of initiation and enlargement of centers, the changes in ground cover resulting from *F. annosus*, and the hazard to park visitors posed by the disease; and (3) to provide interim management alternatives to reduce stand damage and hazard.

OCCURRENCE AND SPREAD OF *FOMES ANNOSUS* IN YOSEMITE VALLEY

In 1971, all developed areas within the Valley were surveyed for dead or dying trees, stumps, or small clearings that might indicate *Fomes annosus*. Aerial photographs, observations from surrounding cliff tops, reports of hazardous-tree incidents, and systematic ground examinations were used to make this survey. In 1975, a less intensive survey was made in undeveloped areas, using mainly aerial photographs and roadside observations.

Each mortality site was examined for conks in old stumps or dead tress. If none were found, isolations were made from root samples from stumps, dead trees, or trees showing symptoms of root damage. Only sites confirmed by conks or by isolation were recorded as *Fomes annosus* centers. Other identified causes of mortality included bark beetle infestation, lightning, uprooting of shallow rooted trees in sites with high water table, and infection by *Armillaria mellea* (another root-disease fungus prevalent in Yosemite Valley but not dealt with in this report).

For purposes of analysis, *F. annosus* centers were categorized as: (1) compact centers involving disease or death of contiguous trees and therefore assignable to a single locus of infection, (2) diffuse centers in which dead and diseased trees were closely grouped but not all contiguous, thus possibly involving more than one locus of infection, (3) multiple centers in which the pattern of mortality clearly indicated more than one locus of infection, but in which confluence of loci precludes accurate recognition of individual loci, and (4) unclassified centers in which patterns of mortality were not determined.

In developed areas, 58 compact, 22 diffuse, 4 multiple, and 22 unclassified centers have been confirmed. In undeveloped areas, 56 unclassified centers have been confirmed. New centers have been found in each year since 1971, and it is likely that they will continue to appear.

All old stumps, dead trees, and live trees were mapped on 69 centers, involving about 88 loci of infection, in 1971. These mapped centers provided a measure of past mortality and a basis for annual monitoring of new mortality and rates of center enlargement (Figure 1). Mortality at the time of mapping ranged from 1 to 139 trees per center and totaled 856 trees. An additional 367 trees have since died or were removed because of advanced symptoms of root decay. Between 1972 and 1976, 15 more centers were mapped, with a total mortality of 184 trees. Thus, the recorded mortality on 84 mapped centers was 1407 trees. Dead pines averaged about 2 feet DBH: dead cedars about 1 foot DBH. Figure 2 shows location and approximate size of centers in one of the Yosemite Valley campgrounds.

Mortality estimates are low because past windthrows do not leave stumps, and, when trees are cut in developed areas, the stumps are usually cut flush with the ground and covered with soil. Several large centers were found in a campground for which a detailed vegetation map was prepared in 1937. Comparison of our 1971 center maps with the 1937 map indicated that, despite careful attempts to locate old stumps, almost half of the pre-1971 mortality was not detected. Since only about half of the confirmed centers have been mapped, and since it is likely that much of the pre-1971 mortality was not detected in mapped centers, the mortality in confirmed *F. annosus* centers probably exceeds 3000 trees.

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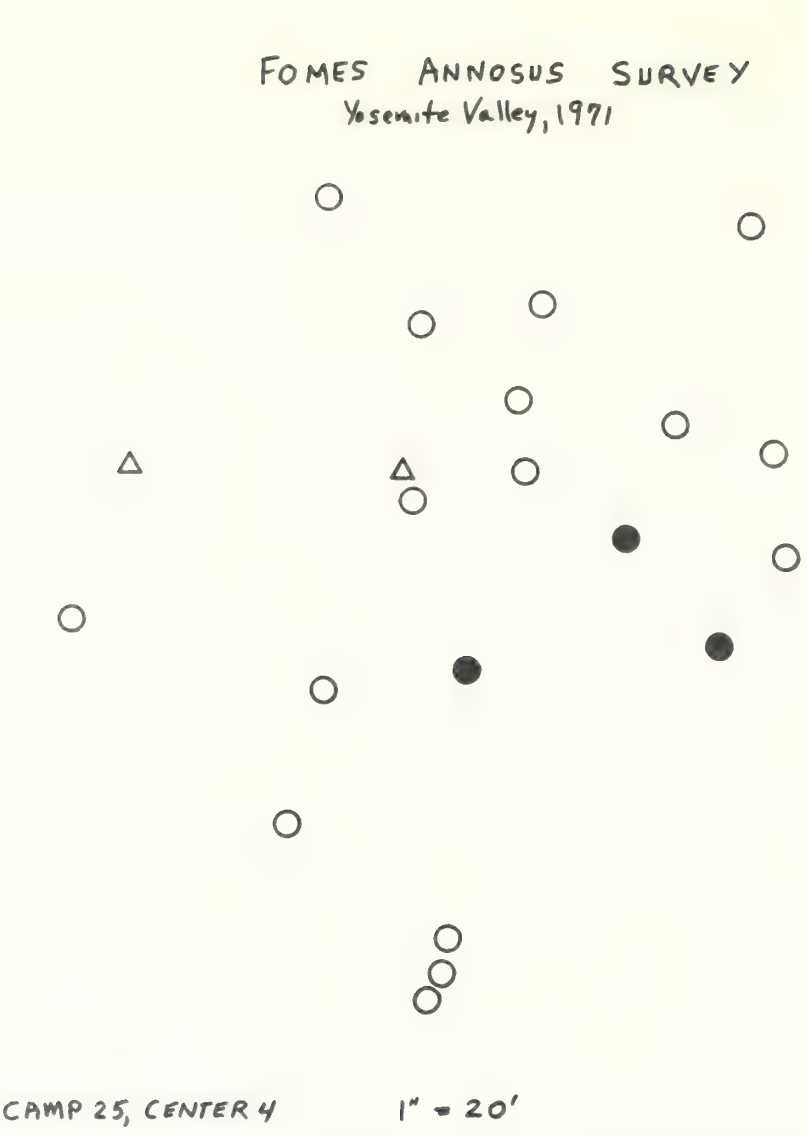

FIGURE 1. Map of *F. annosus* center. Circles are ponderosa pine; triangles are incense cedars. Black circles are dead pines. These maps are used to record annual mortality and disease spread.

The availability of several vegetation maps, prepared at various times between 1937 and 1966, permitted preliminary estimation of the rate of enlargement of *F. annosus* centers. Comparison of past center size with present center size indicated that the radius of most centers increased about 2-3 feet per year, but some appeared to exceed 4 feet per year. Two centers now cover half an acre. At estimated rates of enlargement, many presently small centers will exceed half an acre within 20-40 years, thus denuding large areas occupied by cabins and campgrounds.

Future forest losses depend both on the rate of center enlargement and on the rate at which new centers are being initiated. Since *F. annosus* centers enlarge to encompass more trees with time, the number of trees killed per center provides a measure of relative center age. Frequency distribution of compact centers with few to many trees killed (Table 1) suggests that most centers are young and that the rate of center initiation has increased dramatically in recent years. If this trend continues, many new centers may appear in Valley stands within the next few years. At the present rate of center initiation and enlargement, most of the coniferous forest in Yosemite Valley could be eliminated in a few decades. Further center confirmation and monitoring will be necessary to refine predictions of future losses.

RECOGNITION OF HAZARDOUS TREES

Fomes annosus decays roots of trees, thereby predisposing them to windthrow. In 1960 and again in 1969, falling trees in *F. annosus* centers killed park visitors. Falling trees have frequently damaged autos, cabins, tents, power lines, and other property. Continued use of facilities in stands containing root-rot centers requires means of recognizing and removing infected trees before they fall (Paine 1967, 1971).

Pine are usually, but not always, killed by bark beetles before root decay has progressed sufficiently to make windthrow likely. Incense-cedars, on the other hand, are seldom killed before root decay has progressed to the point where windthrow can occur (Paine). Both species need critical study, but initial work has been focused on cedars.

Sixty-two incense-cedars ranging from 5-37 inches DBH, with crowns ranging from full and vigorous to thin and unthrifty, were uprooted. Root systems were rated for amount of decay by marking decayed roots on a Polaroid photograph. Decay ratings, obtained from the ratio of decayed roots to total roots, were compared to the condition of the crowns. Preliminary analysis indicated that the ratio of live crown to dead crown, the shape of the crown apex (pointed to flat-

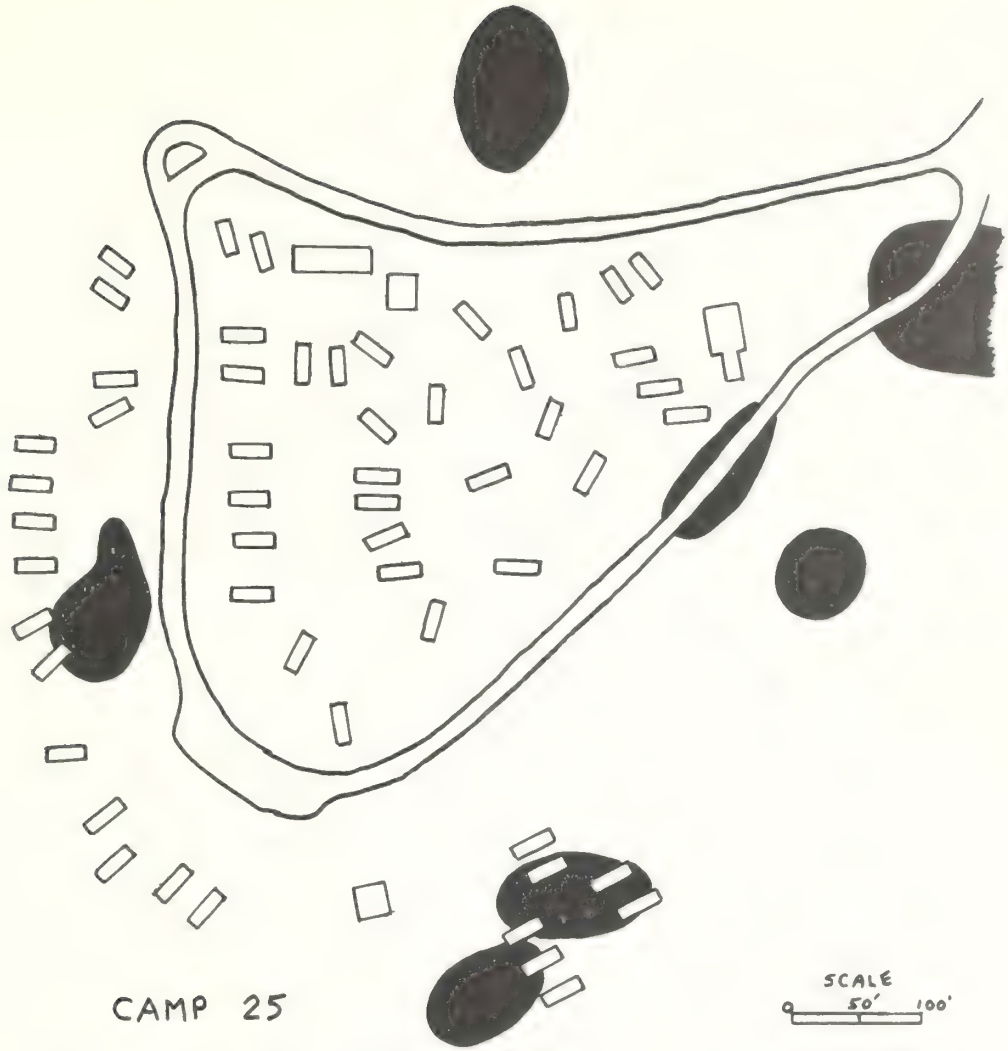

FIGURE 2. Sketch map of Camp 25, showing location and approximate size of *F. annosus* centers (in black).

TABLE 1. Frequency of compact centers with increasing levels of tree mortality.

Numbers of centers	1-5	6-10	11-15	16-20	21-25	26-30	31+
	33	15	3	2	1	3	1

topped), and the vigor of the crown as measured by foliage density were the three factors providing the best indices of root decay. Detailed guidelines for recognition of hazardous cedars are being prepared, and similar studies with pines are planned.

IMPLICATIONS FOR PARK MANAGEMENT

Available evidence suggests that past management decision in Yosemite Valley set in motion a chain of events that resulted in the present *F. annosus* problem. Fire control and grazing led to the establishment of dense stands of pine and cedar. Dense stands led to suppression and general lowering of tree vigor, which in turn led to increased bark beetle infestation. Removal of trees for bark beetle control or to make room for visitor facilities created numerous stumps susceptible to invasion by *Fomes annosus*. From these points of invasion, the disease spread along roots to surrounding trees, providing favorable brood trees for bark beetles and favorable conditions for increased production of spores. A compounding insect-disease problem was thus brought about.

This probable chain of events might have been modified in numerous ways. The establishment of dense conifer stands could have been prevented. Or once established, stands could have been thinned early to promote wide spacing and increased tree vigor, thus reducing bark beetle activity and minimizing opportunities for root-to-root spread of *F. annosus*. Later, stumps could have been treated with borax to inhibit invasion by the fungus, or suppressed and insect-infested trees could have been removed by uprooting. Conifer stands could have been avoided in the development of visitor facilities. Exercise of these options would have required knowledge of disease and insect activity that was not avail-

able to past park managers. Such knowledge is available now.

Fomes annosus is not unique to Yosemite Valley, nor is it the only disease problem that might be encountered by managers of park and recreation forests. A number of root disease, stem decays, dwarf mistletoes, rusts, and other diseases can develop in most Western forests. These can result in loss of forest cover and hazard to visitors. The activity of these diseases can be affected by stand composition, density, vigor, structure, age, and by human activities, all of which can be modified by management.

Today's decisions to manage in various ways, or not to manage at all, will ultimately affect the health and utility of park and recreation forests, the safety of visitors, and the permanence of facilities. Long-range planning can minimize future problems by taking into account the probabilities of disease damage inherent in alternative management strategies.

LITERATURE CITED

BEGA, R. V. 1963. *Fomes annosus.* Phytopathology 53:1120-1136.

GIBBENS, R. P. and H. F. HEADY. 1964. The influence of modern man on the vegetation of Yosemite Valley. Calif. Agr. Exp. Sta. Manual 36. 44 p.

PAINE, L. A. 1967. Accidents caused by hazardous trees on California forest recreation sites. USDA Forest Serv. Res. Note PSW-133. 3 p.

_____. 1971. Accident hazard evaluation and control decisions on forested recreation sites. USDA Forest Serv. Res. Paper PSW-68 10 p.

COMPOSTING - AN ATTRACTIVE AND ECONOMICAL WAY TO RECYCLE URBAN-PRODUCED ORGANIC MATERIALS

J. C. Patterson and J. R. Short[1]

Environmental awareness has become very much in vogue while newspapers and media continually allude to the problem of sewage dispoal, "sanitary" landfill problems, sedimentation, etc. In general, we tend to be a discard society and rely upon dwindling resources to replenish our needs.

This paper deals with one principal area of concern, that of recycling sewage materials, and mentions a second recycling system for other urban produced organics. This problem is of major concern within many of our National Parks as well as any urban area. Director Everhardt of the National Park Service mandated this area of research in 1975 when he stated: "use of biodegradeable and/or recycleable materials will be stressed as much as is practical."

There are two areas within National Capital Region where composting is being conducted: Chesapeake and Ohio Canal National Historical Park, and Rock Creek Park within the District of Columbia.

The C&O project, located at Dargan, Maryland, involves composting of raw sewage materials collected from sanitary facilities within the Piedmont District of the C&O Canal. These sanitary facilities are located along the towpath and supply the visitor need. During previous years, the sewage material was collected and transported to several local townships and deposited within their sewage treatment systems. In general, these systems were rather limited in size and treatment was less than optimal. Therefore, due principally to a limited overload capability, the townships refused Park Service the use of their treatment facilities and the Piedmont District was required to investigate other alternatives. These alternatives were: 1) to close the sanitary facilities along the towpath; 2) transport the sewage out of the District to other municipalities that would accept the material (this situation was tenuous at best and could not be counted upon for long term utilization, and haul distances were excessive); 3) composting. The composting alternative has been advanced by the USDA at Beltsville, Maryland, and has become a very attractive, simple, and economical means of rendering sewage sludge and other organic products into viable organic soil conditions (Epstein et al. 1976; Menzies 1973; Poincelot 1972; Wilson and Walker 1973).

The composting system was explained to the C&O Canal staff and it was agreed to be the best alternative for C&O. The composting site was designed and the program put into effect on June 16, 1976.

Along the 298 kilometer length of the Canal there are approximately 90 sanitary facilities, the bulk of which are located within the Piedmont District. The projected volumes of material for the complete length of the Canal, assuming maximum use of facilities, was 486,000 liters per year. The known volume of production within the Piedmont District for 1975 was approximately 55,000 liters per year. After six months of activity during 1976, we have composted about 27,500 liters of material and could easily handle the projected volumes for the District if necessary. Within the other two Districts, other composting areas could be set up if necessary and are tentatively being suggested as an alternative. This action would be necessitated if those municipalities currently accepting the sewage ceased to do so.

The composting system that Beltsville initially used was a windrow (aerobic) system whereby the materials were laid over a pad (wood chips) in rows, about 3.7 meters wide by 2.4 meters high. The length of the rows was variable but generally much longer than 30 meters. The compost was turned mechanically on a daily basis to maintain the aerobic nature of the mixture and thus the required high temperatures which result from aerobic microbial activity.

This system functioned exceptionally well but was ideally suited to large municipal systems. The equipment needs and land area required for this system are considerable and of necessity, designed for the larger municipal applications. From this larger system then, a smaller design is suggested. The geometry of the windrows is retained and a modification suggested whereby the aerobic nature of the mixture is maintained by a 1/3 hp. blower motor to draw or pull atmospheric oxygen through the pile and ultimately through the blower. (Diagrams 1 and 2). The construction of the pile is as follows.

A mattress of wood chips, compost or other organic material is laid on the pad, the mattress is about 30 cm thick. Into this mattress an oval of 10 cm , flexible perforated drain pipe is placed and joined by a "T" joint. The pipe is installed just beneath the surface of the mattress. The edge of the mattress is upturned to contain the sludge-organic matter mixture. At the "T" connector, a solid section of the flexible pipe is connected to the blower system. Into this solid line, a damper is placed to regulate the amount of air flow. The oxygen percentage-temperature function is an inverse relationship and relatively easily regulated via the damper system.

Adjacent to the compost pad is an area where the organic building agents (wood chips, compost, and saw dust) are placed. Use of these three organic materials is not mutually exclusive of others, in fact, the previously composted material is an excellent bulking material.

A combination of these is mixed and placed on the mixing pad to receive the sewage materials. The sewage is pumped onto the mixed organics and some time allowed for the liquids to be absorbed by the organic materials.

On occasion, when collected volumes of sewage are low, it has been found very desirable to pump the sewage materials into a holding tank at the site until the tank is full and a larger compost pile can be erected. This flexibility does result in some time saving and better utilization of space.

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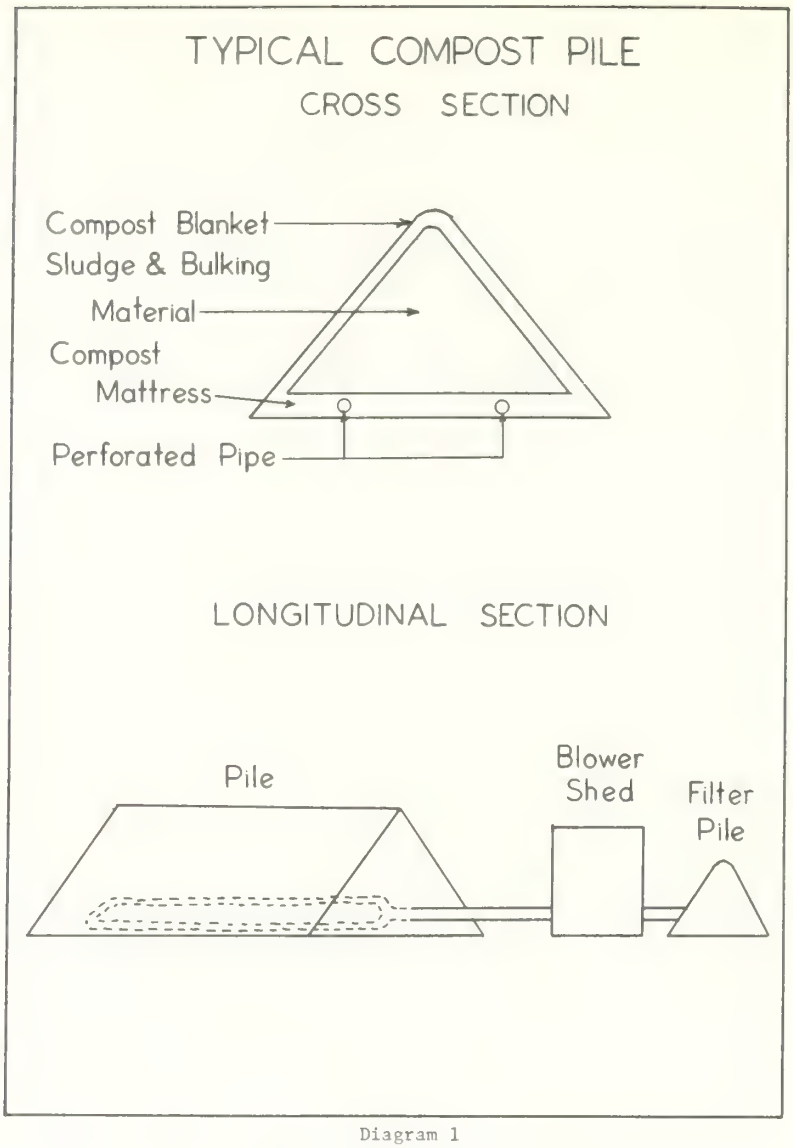

Diagram 1
A typical cross section of
a static pile composting system.

After the absorption period, a front-end loader is utilized to mix and transfer the mixture to the prepared mattress. The materials piled on the mattress at Dargan form a compost pile of about 3.0 x 3.7 x 2.0 meters and contain about 4,300 liters of sewage. The amount of organic materials (which are necessary to absorb liquids and maintain air porosity during composting) utilized in the above compost piles are: sawdust 6.5 cu meters; wood chips - 7.2 cu meters and approximately 4.6 cu meters of previously composted materials. These materials, after placement on the mattress, are covered with a blanket of compost - approximately 5.2 cu meters of compost, or a thickness of 20-30 centimeters. The blanket functions to maintain an insulated cover over the pile and retain microbial heat within the pile and hasten the microbial degradation of the sewage. The blanket remains porous so that atmospheric oxygen can be pulled through to maintain the desired oxygen balance within the pile at 5-15%, and a mid-range temperature is generally desired. These parameters, temperature and oxygen, should be monitored periodically during the initial phases of composting (perhaps 3-5 times per week). Beltsville's research has shown that a temperature of 55°C or above results in large reductions in numbers of fecal and total coliforms and usually in elimination of any salmonella bacteria. The temperature should attain the 55°C level within a 5 day period and rise to as high as 80°C within about 8-10 days. From this plateau, there is a very gradual drop in temperature through perhaps the 25th day to about the 60°C(140°F) level. This drop may continue but we have found that, even after dismantling the compost pile and removing it to the stock pile area, a temperature of about 55°C is maintained for several months or longer, even though the oxygen percentage drops to 0%. The compost will remain in the stock pile area for up to a year or more before used as a soil additive or amendment. Additionally, since there is a demand for organic material as a carbon source and absorbant material, the compost can be reused in the composting operation. The composting action functions due to the microorganisms that feed on the organics (the carbon source) and utilize the nitrogen that is present in the liquid phase and the oxygen as their energy sources. The by-products released then are carbon dioxide and water.

Generally, it has been found that the compost contains approximately 1% nitrogen, 2%+ phosphorus and about 0.2-0.5% phosphate. These values will be, and are, variable but the compost can be used as a low analysis fertilizer material. The pH of the compost is less variable and usually about 6.6 (Table 1).

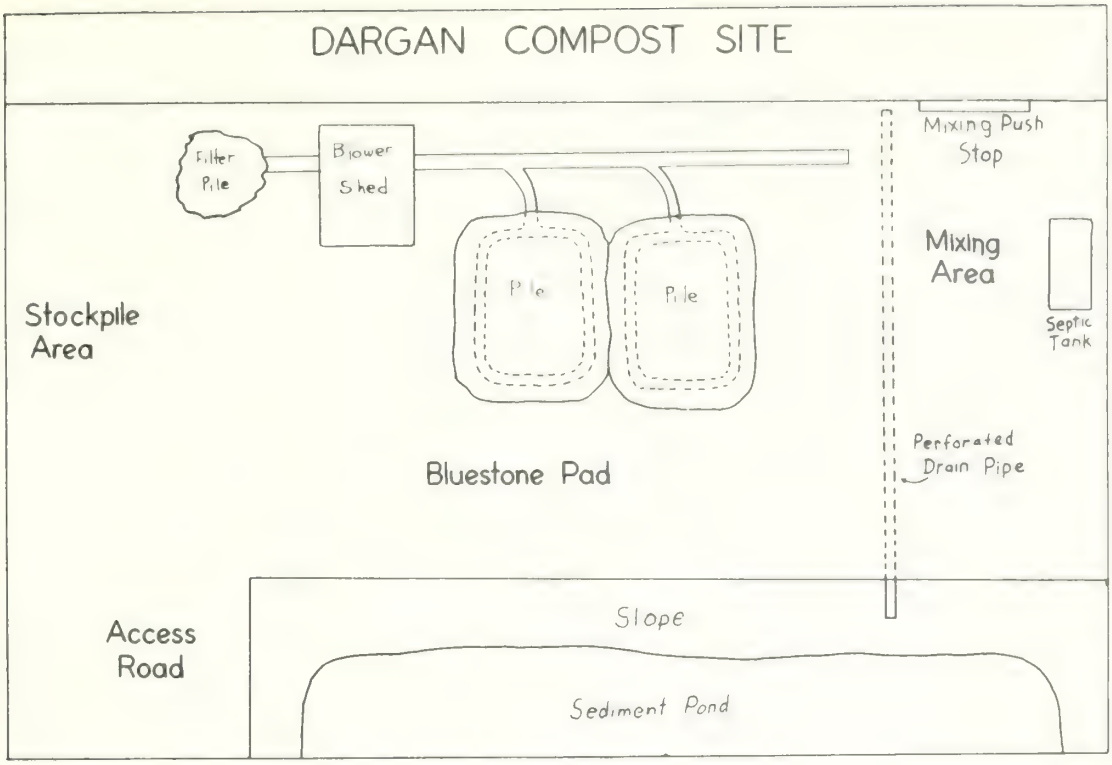

Diagram 2
The composting site at Dargan, Maryland, where composting of raw sewage sludge is practiced. The site is about 1/2 acre in size.

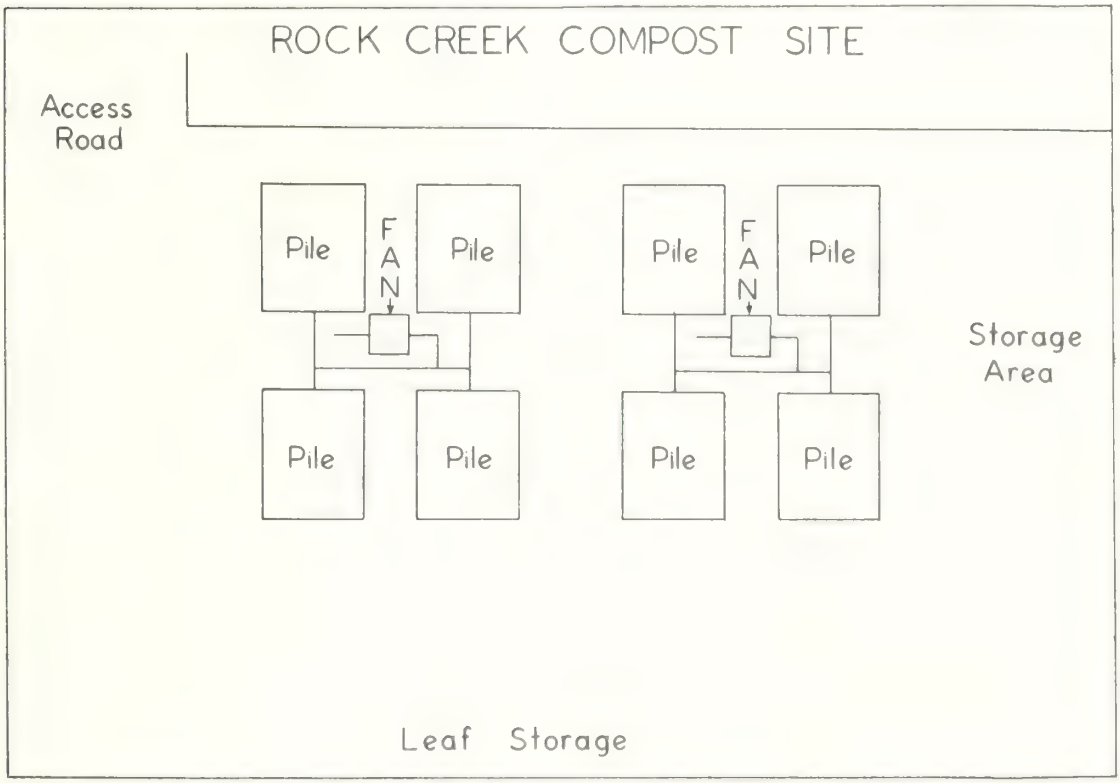

Diagram 3
The experimental composting arrangement at Rock Creek Park. The 8 piles shown are part of the experimental design; as these are phased out, larger compost piles will be utilized here to render a larger volume of usable compost.

Rock Creek Park

Rock Creek Park has for years been the recipient of the annual leaf collection from Northwest Washington, D. C. and has always had an abundant amount of animal manure from the U. S. Park Police and concession stables within the Park. The annual volumes are considerable and create a very real management problem. This summer, a graduate student program was initiated jointly between the Ecological Service Lab and the University of Maryland to design a composting operation and field

TABLE 1. Composition of sludge and compost.*

Component	Digested sludge (%)	Dargan	Screened compost (%)
Dewatered filter cake			
Water	80	95	35
Total Solids	20	< 5	65
Solid Fraction			
pH	Variable	6.1	6.8
Organic matter	50		50
Nitrogen	2.5		0.9
Phosphoric acid	2.7		2.3
Potash	0.6	0.2	0.2
Sulphur	0.9		0.4
Calcium	2.9	2.2	2.6
Magnesium	1.0	1.4	0.3
Boron	23 ppm**		27 ppm
Heavy Metals			
Zinc	2,000 ppm	559 ppm	1,000 ppm
Cadmium	19ppm	4.7 ppm	9 ppm
Copper	600 ppm	149 ppm	250 ppm
Lead	540 ppm	192 ppm	320 ppm
Micro-organisms			
		Dargan	
Total Coliforms	23,000,000,000***	4,980 dry 3,300 wet	97,000 ***
Fecal Coliforms	2,400,000,000***	347 dry 230 wet	3,000 ***
Salmonellae	6,000***		0 ***

*The compostion of digested and composted sludge is subject to considerable variation. Values in the table are approximate averages. Variations in composition occur because of the different wastes discharged, chemical additions, types and degrees of treatment, and bulking materials used.
Data for Digested sludge and Screened Compost : ARS-USDA, Beltsville, Maryland.
**Parts per million
*** Most probable number per hundred grams of sample.

TABLE 2. Experimental compost mixtures.

Pile 1 50% leaves 25% wood chips 25% sludge	Pile 2 50% leaves 50% horse manure
Pile 3 33% leaves 50% horse manure 17% wood chips	Pile 4 45% leaves 34% horse manure 21% paper

study. This portion of the paper will deal with some of the general aspects of this project.

The compost mixtures and composting layout are presented in Table 2 and Diagram 3, respectively. The compost mixtures were designed from principally a carbon/nitrogen ratio and an availability of materials. These organic materials have largely been a "disposal" problem and, with the static pile composting innovation, they can be easily composted and rendered a Park resource.

To date, we have had two replications of composts generated and are just initiating a volume turn-a-round system. The initial replications monitored the functional design of the system and the compost materials are being physically and chemically characterized. The first mixture to be composted in large volume has been the leaf-manure mixture, the pile dimensions are approximately 12 x 4.6 x 2.4 meters. The research work done utilized compost piles that were 2.5-3.0 meters high and about 3.0-4.5 meters wide. The length of the pile varied but was generally 4-5 meters long.

The field plot design is being implemented at present and will test and characterize the soil-compost mixtures and be the subject of the student's Master's Degree program. At present, the researchers are encouraged by the progress and certainly look toward this system to recycle wastes-to-resource.

The ultimate goal with this research work is the full evaluation of various compost mixtures or formulations with regard to composting time and the chemical and physical characteristics of each. The next phase of work involves the field

implementation and evaluation (Patterson 1975). In general, these materials will be targeted for use areas such as picnic grounds, ballfields, trails, etc.

LITERATURE CITED

EPSTEIN, E., G. B. WILLSON, W. B. BURGE, D. C. MULLEN and N. K. ENKISI. 1976. A forced aeration system for composting wastewater sludge. Journal Water Pollution Control Federation. 48:688-694.

EVERHART, G. 1975. Solid Waste Management, USDI Memorandum-Special Directive 75-7: 3pp.

MENZIES, J. P. 1973. Composition and Properties of Sewage Sludge. Paper presented at the 28th Annual Meeting of the Soil Conservation Society of America. Hot Springs, Ark. 9pp.

PATTERSON, J. C. 1975. Enrichment of Urban Soil with Composted Sludge and Leaf Mold; Constitution Gardens. Compost Science: 16:18-21.

POINCELOT, R. P. 1972. The Biochemistry and Methodology of Composting. The Conn. Agri. Exp. Station. Bull. 727. 38pp.

WILLSON, G. B. and J. M. WALKER. 1973. Composting Sewage Sludge: How? Compost Science. 14: 3pp.

UTILIZATION OF URBAN-PRODUCED WASTES FOR SOIL RENOVATION

J. R. Short and J. C. Patterson[1]

Within the urban environment, many waste materials, such as paper, sewage sludge, leaves, wood, etc. are produced. Traditionally, these materials have been disposed of by incineration, burying in landfills, and dumping at sea and in open pits. These methods, due to the danger of polluting the soil, water, and air, and using up valuable land areas for landfills, are constantly becoming more expensive and unpopular. Therefore, new methods of waste disposal should be found, preferably which offer a savings in energy and equipment costs.

One method for disposal of organic wastes which has received considerable attention at National Capital Region, is that of static pile composting. This method was developed by the USDA at Beltsville (Epstein et al. 1976), and has been adapted by National Capital Region. This method produces an organic material similar in appearance to peat moss. This compost can be used as an excellent soil conditioner to provide a lower density of the soil, along with better air and water relationships, increased drainage and infiltration capacity of the soil, and provides some added nutrients to the soil. The compost, however, should not be considered a replacement for fertilizer, even though it is equivalent to a low analysis fertilizer.

National Capital Region, in conjunction with its concern for recycling wastes (Everhardt 1975), is involved with maintaining the beauty of its parks. Therefore, it was felt that this composted material could be used to repair soils damaged by construction activities and visitor use.

The first site National Capital Region utilized compost on a large scale was at Constitution Gardens (Patterson 1975). The site presently occupied by Constitution Gardens is a 16.8 hectare area which previously housed World War I temporary buildings. In the late 1960's, these temporary buildings were torn down, the area received earthy fill material, was seeded with grass seed, and used as an overflow parking lot until construction of Constitution Gardens began in 1974.

The soils present at the site at the time of construction were of very poor quality. These soils had been damaged by construction activities, and by use as a parking lot. The soils were extremely dense and contained much building rubble. The soils in their existing form were deemed unsuitable for supporting the desired landscape planting and would need modification to successfully support Constitution Gardens. There were four basic choices to be considered for modification of the soil: 1. perform no modification at all; 2. modify only the planting holes; 3. modify the soil to a depth of 46 centimeters; or 4. purchase topsoil to cover the site to a depth of 46 centimeters. The third alternative was deemed the most practical solution, and much less expensive than purchasing topsoil for the entire site. It was felt that modification of only the planting holes would result in a "teacup" effect, where water would be trapped in the planting hole, and the roots would not be encouraged to expand into the surrounding soil medium.

Two basic recommendations for the site were developed. The first was a shallow 18 cm modification for turf areas (Figure 1). This was decided upon in order to cut down on expenses, and would not result in impaired performance as turf is a shallow-rooting plant.

For shrub and tree areas, a deeper modification was proposed: the soil was modified in these areas to a depth of 46 cm. This was done in order to insure a satisfactory rooting medium for these plants which are deeper rooting species than turf (Figure 2).

Construction of Constitution Gardens began in the late fall-early winter of 1973 with preliminary grading. The contours and lake were next shaped, and the organic materials were stockpiled nearby. The organic materials used consisted of composted sewage from the USDA at Beltsville, containing (three parts wood chips, and one part sewage sludge), leaf mold, and fresh leaves.

After the site had been graded to approximately the final contours, the organic materials were spread out in a layer over the surface (except in the areas where walkways would be built) and mixed with the subsoil. The mixing was accomplished by tilting the blade of a bulldozer to a 45 degree angle, and pushing it through the materials. Unfortunately, due to an unusually wet season, the materials were not mixed as well as desired. A solution to this difficulty in the future could perhaps be found in off-site mixing of the organic materials with the soil and then being applied to the surface.

A comparison of the soil surface before and after modification indicates that the surface of the amended soil is much looser and contains more organic matter than the unamended soil surface. This should result in a much more favorable soil environment for plants. After the mixing operation was completed, a surface application of topsoil approximately 10 cm thick was applied. It was felt this would eliminate the problem of wood chips (from the composted sewage sludge) interfering with mowing and other operations. However, another problem was created: compaction of the surface soil.

The topsoil applied was generally not an ideal material, and vehicular traffic over the surface compacted the material. To alleviate this problem the surface was scarified prior to introduction of turf. After tree planting, the site was seeded, although areas where grass was needed quickly were sodded.

The most significant problem area at Constitution Gardens has been an excess of water, mostly concerning trees which were planted within the walkways. The walks were built upon a dense subbase, which received no soil renovation (to ensure a solid base for the walks). The trees, by being surrounded by this dense base, were essentially in a "teacup," which accumulated water and eventually led to the death of the trees. A similar problem occurred in a few places outside

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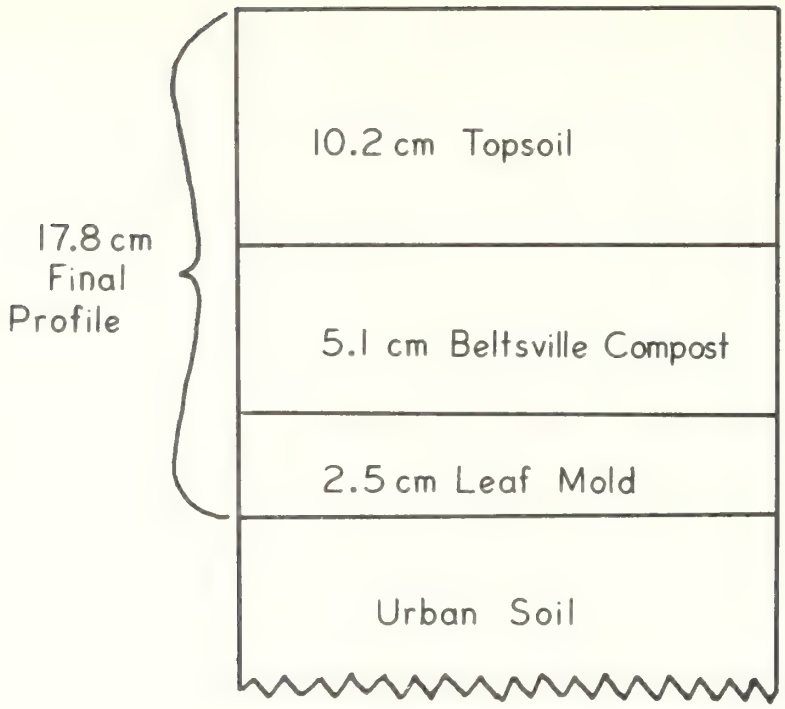

FIGURE 1. Modified soil profile--turf.

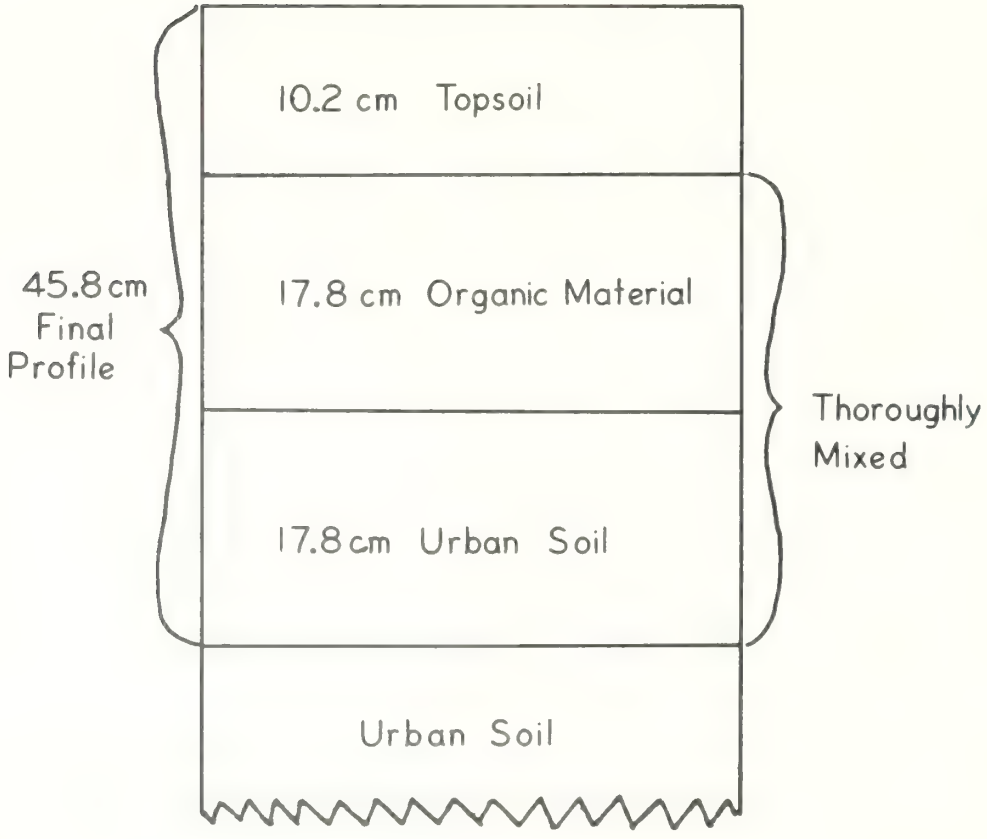

FIGURE 2. Modified soil profile--trees amd shrubs.

of the walks, where the tree had sunk in its planting hole, and excess water was allowed to collect.

A comparison of cost figures for Constitution Gardens indicates the savings realized by modification of the soil. The cost of modification was $205,584, while the cost of 12 inches and 18 inches of topsoil was $272,250 and $408,375, respectively. The cost of topsoil was only for transportation to the site and included no other modifications that may have been needed. A considerable savings resulted from the use of compost to modify the soil.

The overall effect of Constitution Gardens is quite pleasing, and the plants should continue to become established and provide a large pleasant park in an area which used to be quite barren.

The second major area of concern to National Capital Region was the site of the Festival of American Folklife. Because 1976 was the Bicentennial year, the period of operation of the Folklife Festival was extended from a two week period during the summer to the three month period from Memorial Day to Labor Day. It was fairly obvious that it would be impossible to keep turf viable in the area, due to the extended period of operation and the increased number of visitors, approximately 10,000 per week. Therefore, wood chips were broadcast over the site to a depth of approximately 6-8 cm. The wood chips would lessen compaction of the already dense soil, and provide a more pleasant surface for visitors, especially in rainy weather.

The problem which confronted National Capital Region was how to restore the area to turf after the Folklife Festival had concluded. The Ecological Services Lab set up a series of test plots during the year preceding the operation of the Festival to determine which of various renovation techniques provided the best medium for turf grass establishment. The plot arrangement is as follows:

Plot #1: Control. Seed directly over wood chips.

Plot #2: Rake off wood chips, till, and seed.

Plot #3: Apply 6-13 mm of Beltsville Compost (23-46 metric T/ha) chips, till, and seed.

Plot #4: Rake off wood chips, till, and apply 6-13 mm Beltsville compost and seed.

Plot #5: Roto-till and seed.

Plot #6: Apply 6-13 mm Beltsville compost over wood chips and seed.

Based on the results of the test plots, it was decided to evenly distribute the wood chips over the site, fertilize with 1/2 soil test recommendation of 24-4-8 fertilizer, apply 2.5 cm Beltsville compost, till the site thoroughly, smooth, seed, and top dress fertilize with the remainder of the 24-4-8 fertilizer. The high nitrogen values were required to balance the high carbon: nitrogen ratio present in the wood chips.

A comparison of costs for restoring the Festival of American Folklife site demonstrates the savings realized by the use of compost. The cost for the entire restoration was $58,000, while the cost for sod alone would have been $300,000.

Seed germination has been retarded due to abnormally cold weather, although approximately 25% germination is present. We anticipate further germination in the spring, with the possibility that a light over seeding may be necessary in order to obtain maximum turf establishment.

Our work at both Constitution Gardens and the Festival of American Folklife has convinced us that the use of composted organic "wastes" is both practical and economical. The use of these materials in this manner will supply a product for use in park maintenance (as well as in other areas) and help to solve the waste disposal problem facing our urban areas.

LITERATURE CITED

EPSTEIN, E., G. B. WILLSON, W. D. BURGE, D. C. MULLEN and N. K. ENKIRI. 1976. A Forced Aeration System for Composting Wastewater Sludge. Journal Water Pollution Control Federation 48(4):688-694.

EVERHARDT, G. E. 1975. Special Directive 75-7: Solid Waste Management. USDI 3 pp.

PATTERSON, J. C. 1975. Enrichment of Urban Soil with Composted Sludge and Leaf Mold - Constitution Gardens. Compost Science 16(3):18-21.

USE OF COMPOSTED SEWAGE SLUDGE FOR THE ESTABLISHMENT OF TURFGRASS SOD[1]

Jay S. Angle[2], Duane C. Wolf[2] and John R. Hall III[3]

INTRODUCTION

The use of sewage sludge compost as a soil amendment presents a method of solving a waste disposal problem in the National Park System while simultaneously providing a valuable product which can be used to improve both the chemical and physical properties of most soils (Epstein et al. 1976; Bengtson and Corvette 1973). Potential for the utilization of sewage sludge compost on turfgrasses exists in recreation areas and picnic grounds, and around prominent landmarks and monuments. Compost utilization could be an effective means of supplementing the fertilizer program in these areas.

The composting of sewage sludge has recently been under active investigation (Terman et al. 1973; Kirkham 1974). The effects of soil amendment with sewage sludge compost on the nutrient, heavy metal content and yield of corn, soybeans, and swiss chard has been reported (Chaney et al. 1975). However, comparable data for turfgrasses are lacking.

The objectives of this experiment were: 1) to compare the effects of soil amended with five rates of composted sewage sludge on the color, quality, growth rate, sod pulling strength and nitrogen and phosphorus content of two types of turfgrass sod, and 2) to assess the soil physical and chemical status following compost addition.

MATERIALS AND METHODS

Composted Sewage Sludge

The compost used in this experiment was provided by the U. S. Department of Agriculture, Agricultural Research Service, Biological Waste Management and Soil Nitrogen Laboratory, Beltsville, Maryland and the Maryland Environmental Service, Annapolis, Maryland. The compost consisted of digested sewage sludge and wood chips in a ratio of 1 to 2.5, respectively. Following the composting period, the wood chips were removed by passing the compost through a rotating screen. An analysis of the composted sewage sludge is presented in Table 1. The percent moisture and volatile material are 40% and 30%, respectively. The heavy metal concentrations found in the compost are within the acceptable limits for composted sewage sludge published by Shipp and Baker (1975). The compost was applied to the soil at rates of 0, 90, 180, 360, and 720 mT/ha and incorporated to a depth of 15 cm.

Soil

The soil utilized in this study was a Sassafras sandy loam (Typic Hapludult, fine loamy, siliceous, mesic). Prior to compost addition, the soil had a cation exchange capacity of 5.4 meq/100g, pH 5.1 and the percentage of sand, silt, clay and organic matter was 59.6, 35.2, 5.2, and 1.33, respectively.

Soil samples were collected one year after compost addition and analyzed for pH, extractable Mg, P, and K by standard soil test procedures (Rivard and Bandel 1975). Soil samples were also collected periodically for determination of bulk density and percent water by standard techniques (Blake 1965; Gardner 1965).

Turfgrasses

The two turfgrass sods used in this experiment were commercially available Kentucky bluegrass (*Poa pratensis* L.) which was a mixture of 30% Merion, 30% South Dakota Certified, 30% Fylking, and 10% red fescue (*Festuca rubra* L. cv. Pennlawn), and, secondly, 90% Kentucky-31 tall fescue (*Festuca arundinacea*) and 10% South Dakota Certified Kentucky bluegrass. The sodding date was November 20, 1975 and the sod was maintained at a height of 5.7 cm by mowing twice monthly. Clippings were collected during mowing, dried to a constant weight, and used to determine the growth rate of the turfgrasses. Twice monthly the color and quality of the turfgrasses were determined by rating on a scale of 0 to 9 with 6 being the acceptable and 9 being the highest. During March and September 1976, clipping samples were also analyzed for total nitrogen by the Kjeldhal procedure (Nelson and Sommers 1973) and for phosphorus. At time periods of one and three months after sod establishment, sod pulling strength was also determined by procedures previously reported (King and Beard 1969).

The experimental design for this experiment was a completely randomized block with a single split, replicated three times. The compost rate was the main plot and turfgrass species was the sub-plot. The sub-plot size was 3 m x 1.5 m.

RESULTS AND DISCUSSION

Turfgrasses

Turfgrass color and quality data are presented in Table 2. The results indicate that the addition of compost increased the color rating for Kentucky bluegrass at rates up to and including 360 mT/ha. The Kentucky-31 tall fescue exhibited increased color ratings throughout the compost rates tested and was highest at the 720 mT/ha rate. The quality ratings also showed that the addition of compost resulted in higher quality turfgrass. Both turfgrasses were rated highest at 720 mT/ha of compost treatment. Some or all of the increase in color and quality most likely resulted from an increase in available nitrogen supplied by the compost. The soil water holding capacity, temperature, and bulk density were favorably altered by the addition of compost and these factors may also have had an influence on the color and quality ratings of the turfgrasses.

[1]The authors would like to acknowledge the technical assistance of Gwen McClung, Scott Stanley, Steve Kiracofe, and Ron McCormick. Financial assistance for this project was provided by the U. S. Department of Interior, National Park Service under contract number CX 3000-5-1228 and is gratefully acknowledged.

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TABLE 1. Elemental analysis of a composite sample of the composted sewage sludge used in the turfgrass sodding experiment.

Element	Concentration (dry weight basis)
	%
N	1.60
P	2.57
K	0.91
Ca	3.84
Mg	1.68
Fe	7.68
Al	4.70
	ppm
B	16
Cd	12
Cu	430
Mn	1,360
Na	705
Ni	128
Zn	1,370

lateral shear strength may be reduced in soils amended with high rates of sewage sludge compost For this reason, the use of high rates of compos for the establishment of areas such as athletic fields may not be a desirable practice.

Foliar nitrogen and phosphorus levels are presented in Table 5. Results indicate that the addition of compost to the soil increased the phosphorus content of both turfgrasses. Kentuck 31 tall fescue exhibited increased nitrogen content with increased compost addition, but Kentuc bluegrass did not follow this trend.

Soils

Extractable nutrient levels and soil pH are presented in Table 6. Soil pH was raised from 5.6 to 6.0 with the addition of 720 mT/ha of compost. Magnesium and phosphorus were increased as a result of compost addition. Highest levels in the soil for each element were found at the highest compost addition rate. The level of potassium, however, was not increased with the addition of compost. Compost was shown to contain very little potassium (Table 1), thus change in the concentration of soil potassium would not be expected.

The addition of compost to the soil resulted in a decrease in the bulk density of the soil (Figure 1). A high correlation was found between bulk density and compost addition as indicated

TABLE 2. Mean color and quality ratings of Kentucky bluegrass and Kentucky-31 tall fescue sod on a sassafras sandy loam soil amended with five rates of composted sewage sludge. The data were collected from March 3, 1976 to September 30, 1976.

	Compost Rate (mT/ha)				
Turfgrass	0	90	180	360	720
	Color Rating				
Bluegrass	6.8 ± 0.9[1/]	7.3 ± 0.7	7.5 ± 1.0	8.0 ± 0.8	7.9 ± 1.1
Tall Fescue	6.9 ± 0.9	7.3 ± 0.9	7.7 ± 1.1	7.7 ± 0.9	8.3 ± 0.7
	Quality Rating				
Bluegrass	6.5 ± 0.8	7.5 ± 1.0	7.6 ± 0.6	7.9 ± 0.5	8.3 ± 0.9
Tall Fescue	6.9 ± 0.9	7.4 ± 0.8	7.5 ± 0.5	7.7 ± 1.0	8.3 ± 0.6

[1/] All values are presented as the mean ± one standard deviation.

Growth rates of Kentucky bluegrass and Kentucky-31 tall fescue were increased by the addition of compost (Table 3). Maximum growth occurred for both grasses when 720 mT/ha of compost had been incorporated into the soil. Varying growth rates over time were attributed to changes in the climate. During favorable growing conditions, the turfgrasses responded to the additional nitrogen more readily than during adverse climatic conditions.

No discernible trend was evident between sod pulling strength and compost addition (Table 4). This may be due to the method of analysis since the technique utilized is directly influenced by the mass of the soil adhering to the plant roots as well as the strength of binding between the plant root and the soil matrix. In this study, the addition of sewage sludge compost resulted in a dramatic reduction in soil bulk density (Figure 1). This reduction in bulk density would thus tend to reduce the sod pulling strength as measured in this experiment. These data also indicate that the traffic bearing strength or

by an r^2 value of 0.88 for Kentucky bluegrass and a value of 0.76 for Kentucky-31 tall fescue. A bulk density of 1.45 g/cm^3 was reduced to 0.85 g/cm^3 by the addition of 720 mT/ha of compost to the soil in the Kentucky bluegrass plots. This lower bulk density resulted in increased air and water movement in the soil, as well as decreased the mechanical resistance to the growth of roots.

Figure 2 represents the linear regression line plotted for compost additions versus percent water by weight of the soil. An r^2 value of 0.86 indicates a good correlation between compost rate and percent soil water for Kentucky bluegrass, while the data for Kentucky-31 tall fescue exhibited a slightly lower r^2 value.

CONCLUSIONS

Preliminary results from these experiments indicate that the addition of composted sewage sludge at rates up to 720 mT/ha for the establishment of Kentucky bluegrass and Kentucky-31 tall fescue sod resulted in increased color, quality

TABLE 3. Growth rate of Kentucky bluegrass and Kentucky-31 tall fescue sod on soil amended with five rates of composted sewage sludge and sampled at various times.

Date	Turfgrass	Compost rate (mT/ha) 0	90	180	360	720
		g/m^2 day				
5-6-76	bluegrass	2.75	2.62	3.44	3.58	3.07
	tall fescue	2.60	3.22	3.91	4.07	4.64
6-14-76	bluegrass	1.37	2.17	4.21	4.07	4.97
	tall fescue	1.99	2.46	4.79	5.39	5.76
7-13-76	bluegrass	3.07	5.45	4.51	6.01	7.20
	tall fescue	4.53	6.54	5.29	5.78	6.81
8-13-76	bluegrass	1.97	3.31	4.07	3.52	4.46
	tall fescue	2.89	2.19	2.74	3.13	3.34
9-10-76	bluegrass	1.12	1.18	1.64	1.22	1.33
	tall fescue	1.64	2.03	2.88	2.58	2.16
10-18-76	bluegrass	1.46	1.78	2.20	2.63	2.34
	tall fescue	1.98	2.47	3.22	3.14	3.77

TABLE 4. Sod pulling strength of Kentucky bluegrass and Kentucky-31 tall fescue sod on soil amended with five rates of composted sewage sludge and sampled at two dates.

Time After Sodding (Days)	Turfgrass	Compost Rate (mT/ha) 0	90	180	360	720
		kg/m^2				
30	Bluegrass	165	123	150	140	77
	Tall fescue	84	95	86	81	118
110	Bluegrass	709	969	875	793	819
	Tall fescue	533	721	635	465	436

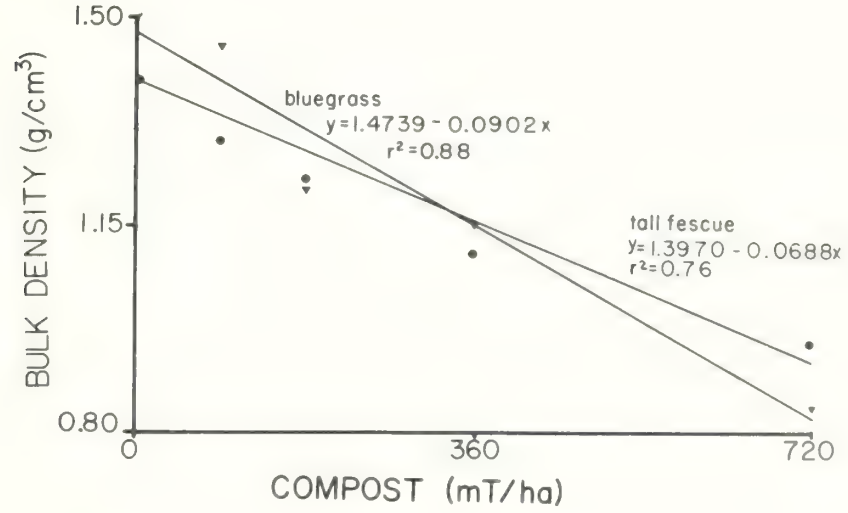

FIGURE 1. Linear regression analysis of compost addition versus bulk density. Samples were collected 118 days after sodding.

TABLE 5. Nitrogen and phosphorus analysis of bluegrass and tall fescue samples collected 100 days after sod establishment on soild amended with five levels of composted sewage sludge.[a]

Compost Rate (mT/ha)	Turfgrass	Nitrogen	Phosphorus
		%	
0	tall fescue	3.95 ± .20	.40 ± .03
	bluegrass	4.24 ± .77	.36 ± .00
90	tall fescue	3.73 ± .28	.39 ± .03
	bluegrass	3.55 ± .07	.38 ± .03
180	tall fescue	4.32 ± 1.18	.43 ± .04
	bluegrass	4.14 ± .67	.48 ± .06
360	tall fescue	4.46 ± 1.27	.41 ± .05
	bluegrass	4.00 ± .24	.43 ± .03
720	tall fescue	5.07 ± .82	.45 ± .07
	bluegrass	4.24 ± .10	.46 ± .07

[a]Values are presented as the mean ± one standard deviation.

TABLE 6. Extractable nutrient levels and soil pH of a sassafras sandy loam amended with five rates of composted sewage sludge.[a]

Parameter	Compost Rate (mT/ha) 0	90	180	360	720
pH	5.6	5.7	5.9	5.9	6.0
Mg (ug/g)	135	205	259	296	300+
P (ug/g)	152	292	399	458	496
K (ug/g)	226	218	210	217	238

[a]Soil samples were collected one year after compost addition.

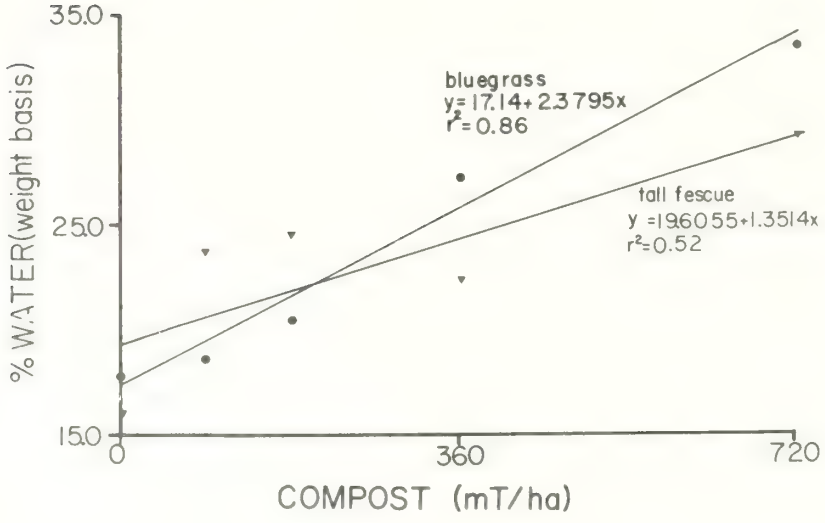

FIGURE 2. Linear regression analysis of compost addition versus % water by weight. Samples were collected 118 days after sodding.

and growth rate. The addition of compost to the soil used in this experiment increased the levels of extractable magnesium and phosphorus in the soil. Incorporating compost into the soil resulted in decreased soil bulk density and an increase in percent water by weight.

These preliminary results indicate that the use of composted sewage sludge in the establishment of turfgrass sod has the potential to be a useful management practice. However, the loss of lateral shear strength and the long term effects should be evaluated.

LITERATURE CITED

BANDEL, V. A. and C. E. RIVARD. 1975. Soil testing methods. Univ. of Md. Mimeo. 37.

BENGTSON, G. W. and J. J. CORNETTE. 1973. Disposal of composted municipal waste in a plantation of young slash pine: effects on soil and trees. Jour. Environ. Quality. 2(4):441-444.

BLAKE, G. R. 1965. Bulk density. p. 375-377. *In* C. A. Black (ed.). Methods of soil analysis. Amer. Soc. Agron. Jour., Madison, Wisconsin.

CHANEY, R. I., M. C. WHITE and P. W. SIMON. 1975. Plant uptake of heavy metals from sewage sludge applied to land. Proceedings of the 1975 National Conference of Municipal Sludge Management and Disposal. EPA, Anaheim, Calif. pp. 169-178.

EPSTEIN, E., J. M. TAYLOR and R. I. CHANEY. 1976. Effects of sewage sludge and sludge compost applied to soil on some soil physical and chemical properties. Jour. Environ. Quality. 5(4):422-426.

GARDNER, W. H. 1965. Water content. pp. 84-96. *In* C. A. Black (ed.). Methods of soil analysis. Amer. Soc. Agron. Jour., Madison, Wisconsin.

KING, J. W. and J. B. BEARD. 1969. Measuring rooting of sodded turfs. Agron. Jour. 61(3): 497-498.

KIRKHAM, M. B. 1974. Disposal of sewage sludge on land: effects on soil, plants, and ground water. Compost Science. 15(2):6-10.

LERICHE, H. H. 1968. Metal contamination of soil in the Woburn Market-garden experiment resulting from application of sewage sludge. Jour. of Agric. Science., Cambridge. 71:205-208.

NELSON, D. W. and L. E. SOMMARS. 1973. Determination of total nitrogen in plant material. Agron. Jour. 65(1):109-112.

SHIPP, R. F. and D. E. BAKER. 1975. Pennsylvania's sewage sludge research and extension program. Compost Science. 16(2):6-9.

TERMAN, G. L., J. M. SOILEAU and S. E. ALLEN. 1973. Municipal waste compost: effects on crop yields and nutrient content in greenhouse pot experiments. Jour. Environ. Quality. 2(1):89-92.

WALKER, J. M. 1975. Sewage sludge - management aspects for land application. Compost Science. 16(2):12-21.

SOIL COMPACTION--EFFECTS ON URBAN VEGETATION

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MODIFICATION OF BULK DENSITY ON SANDY LOAM AND SILTY LOAM SOILS IN WASHINGTON, D. C.

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As the population of urban areas increases, it is necessary for these urban areas to expand into principally agricultural areas. The building operations involved, such as bulldozing, result in destruction of the structure of the soil with a resulting increase in compaction of the soil. The plant mortality, drainage problems, and erosion found in urban areas can often be attributed to the increased compaction of the soil. The importance of compaction has led to research involving the use of several amendments to reduce the amount of compaction. Compaction is the result of heavy impact upon soils producing a compressive force that markedly reduces the pore space and porosity while forcing the soil particles (sand, silt, and clay) into a closer proximity with each other. This occurrence can take place in recreation areas (trails, ballfields, etc.) or special event areas where the soils or fragile turf and plants are exposed to impact.

Compaction of the soil leads to some very serious effects. The more well-known effects of compaction include a reduction in pore space, available moisture, and moisture absorption; as well as increase in thermal conductivity, run-off and erosion, mechanical impedance, hydrophobicity, and carbon dioxide percentage of the soil atmosphere. Of these effects, the most serious is the reduction in the amount of pore space in the soil. As the soil is compacted, the amount of large pores (macropores) is dramatically reduced, leaving only the micropores. The reduction in the number of macropores results in a decrease in the amount of water available for plant use by increasing the percentage of water that is held tightly within the soil matrix. Because the macropores have been reduced, the soil cannot readily absorb water from rainfall and irrigation; likewise, the water that is present cannot readily drain from the soil matrix (Jamison 1953).

Some of the other more dramatic effects of compaction on soils and plants are as follows:

1) Because the soil particles are in closer proximity, the soil warms and cools more quickly when dry; and when wet, the process is slower. In the spring, this results in delay in seed germination, as well as slower plant metabolic activity.

2) The reduction in moisture absorption naturally causes an increase in run-off, and increases the erosion of the soil.

3) Plant roots are impeded in their penetration of the soil matrix by the relative increase in solid mineral matter present.

4) Related to the lower moisture absorption is the phenomenon of hydrophobicity. Not too much is known of this property of compacted soils; but when the soils are dry, there is an apparent resistance to the absorption of water applied to the surface. Initially a ponding may be present on the surface until the hydraulic head becomes great enough to "force" the entrance of water into the soil surface.

One of the most significant effects upon pla of the reduction in pore space is the increase the carbon dioxide content of the soil atmosphe (Jamison 1953). The reduced pore space impedes the rate of gaseous exchange with the atmospher The soil organisms, by their respiration, utilize what little oxygen is available to produce carbon dioxide. The lower oxygen content and i creased carbon dioxide has marked effects upon the elongation of roots and respiration of plan

Because of these significant effects of the compaction of the soil, it is desirable to redu the compaction and increase the pore space. Bu density is used as the parameter for measuring compaction, because pore space can be found directly by utilizng the particle density of the soil. The calculation is: (1 - B.D./P.D.) x 10 The most practical method of increasing the por space is to incorporate various amendments into the soil (Kijne 1967). Many amendments have be used in the past, including organic materials, such as: woodchips, leaf mold, composts, and sa dust; and inorganic materials such as: coarse sand, sintered fly ash, expanded slate, ashes, vermiculite and calcined clay (Bredakis 1966; Engle-Capp 1967).

The decision to modify the soils in an area should be based on three important consideratio 1) the area under consideration should be of economic value (ex. recreation areas), 2) the amendments themselves should be effective for a least 10 years, especially if the area contains trees, 3) the amendments should be inexpensive and locally available.

When purchasing an amendment, thought should be given to the fact that what is actually bein purchased is the pore space of the amendment. Therefore, the amendment should be of rigid structure (to resist mechanical breakdown) and have a large amount of inherent pore space. Sintered fly ash and expanded slate meet both c these considerations and were chosen as amendments in our research. Coarse sand was chosen to compare its effectiveness with that of the sintered fly ash and expanded slate. In additi sewage sludge was added to determine its effect upon bulk density and organic matter percentage Vermiculite, calcined clay, and others, while having a large amount of pore space, compress easily, were expensive, and therefore not chose for this study. The organic amendments were nc used because of their relatively short life; ho ever, such amendments are very useful for incre ing the fertility and water-holding capacity of the soil and should be used during the regular maintenance operation.

Each amendment used was assigned a treatment number, and randomized according to the Randomized Complete Block design. Each treatment was replicated three times.

Two soil types were chosen for the study--a

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TABLE 1. Bulk density after eight years of recreational use.

Treatment and bulk density on silty loam soil			
Treatment	Ave. B.D.	Pore space	DNMRT
	G/CC	%	.05
33% ES	1.39	47.55	D
20% ES	1.41	46.79	D
33% SFA	1.42	46.42	C
20% SFA	1.44	45.66	C
UD control	1.51	43.02	B
RT control	1.51	43.02	B
20% CS	1.54	41.89	A
33% CS	1.56	41.13	A

ES = expanded slate; SFA = sintered fly ash; UD control = undisturbed control; RT control = roto-tilled control; CS = construction sand; DNMRT = Duncan's New Multiple Range Test.

TABLE 2. Bulk density after seven years of recreational use.

Treatment and bulk density on sandy loam soil			
Treatment	Ave. B.D.	Pore space	DNMRT
	G/CC	%	.05
33% ES	1.17	55.85	D
33% SFA	1.19	55.10	CD
20% ES	1.23	53.59	BCD
20% SFA	1.24	53.21	BC
UD control	1.29	51.32	B
RT control	1.40	47.17	A

ES = expanded slate; SFA = sintered fly ash; UD control = undisturbed control; RT control = roto-tilled control; DBMRT = Duncan's New Multiple Range Test.

silt loam and a sandy loam. The complete design was used on each site, with the exception of coarse sand, which was not used on the sandy loam site. A clay loam soil was also desired, but one utilized as a recreation site could not be located.

Bulk density was determined by the clod method and the core method (Blake 1965). The clod method is generally preferred because an intact, relatively undisturbed clod is taken from the soil and preserved. Therefore, the bulk density of the clod is assumed to be more nearly like the actual field conditions than another method. However, the core method was used on the sandy loam site because a soil clod would not hold together due to the high sand content. This accounts for the slightly lower values for bulk density obtained at this site. Percent pore space was calculated using an assumed particle density of 2.65 g/cc; the density of quartz.

Infiltration rates were determined using double ring infiltrometers (Haise et al. 1956); however, the results were generally inconclusive. We feel this is due to the necessity of running all infiltrations at the same moisture content and temperature, a physical impossibility considering the large number of plots to be tested.

The values obtained for bulk density on the silty loam soil are illustrated in Table 1. The plots which were modified using the expanded slate exhibits the lowest bulk densities, although there is no significant difference between the 20% and 33% treatments. The values obtained for the controls indicate that roto-tilling does not significantly affect the bulk density of the silty loam soil. The values for coarse sand added to the soil indicate that the bulk density was actually increased by the addition of these materials.

The results obtained on the sandy loam soil were slightly different than those obtained on silty loam soil (Table 2). In this series, the 33% treatments of sintered fly ash and expanded slate reduce the bulk density to a slightly greater degree than the 20% treatments. The roto-tilling operation has significantly increased the bulk density as compared to the undisturbed control.

In order to make a specific recommendation of which amendment to apply to a soil in order to reduce its bulk density, the type of soil present must be known. Also, another major factor to consider is one of economics. To begin with, the area to be modified must be of value for intense public use, and budget limitations will dictate how much of the amendment can be purchased. For example, on the silty loam soil, the maximum effect seems to be obtained using the 33% treatment of expanded slate; however, because there is no significant difference between the 33% treatment and the 20% treatment, for economic reasons the 20% treatment would be preferred. The addition of coarse sand to improve the bulk density of the silty loam soil should be avoided as it seems to increase the bulk density of the soil. Although roto-tilling the silty loam soil does not significantly alter the bulk density, it is to be preferred to no treatment at all because it provides a better seedbed medium for turf establishment.

The sandy loam soil, due to its coarser texture, seems to require slightly different consideration. The maximum reduction of bulk density appears to be obtained with the 33% expanded slate, although there is no significant difference between it and the 33% sintered fly ash and the 20% expanded slate. The data would seem to indicate there is no significant difference between the 20% expanded slate, 20% sintered fly ash, and the undisturbed control. On this basis, therefore, it would not be economically feasible to modify this soil using either the 20% expanded slate or the 20% sintered fly ash. On the sandy loam soil, roto-tilling alone significantly increased the bulk density of the soil, probably due to the more complete destruction of the soil structure than that which occurred in the silty loam soil.

Sewage sludge was used as an organic amendment on one half of the plots: the plot number was doubled and sewage sludge was applied to one half of the plots to determine if sewage sludge had any effect upon the bulk density. It was found that, on both the silty loam soil and the sandy loam soil, there was no significant difference in either the bulk densities or the organic matter percentages obtained.

The compaction of soil in the urban ecosystem is a serious and pervasive problem. The reduction of the bulk density, with a corresponding increase in the amount of pore space present, should be of prime importance to urban use planner. An increase in pore space will result in faster water intake into the soil (with an increased drainage capability), reduced erosion potential, a more aerobic environment, and a better medium for root expansion and plant establishment. Various amendments can be incorporated into the soil to improve the bulk density; two of which provide a lower bulk density are sintered fly ash and expanded slate. Coarse sand apparently increases the bulk density of the two soil types tested and is not recommended for alleviation of compacted conditions. Economics

should be considered when deciding to modify an area, and the type of soil to be modified should be considered when choosing a modifier.

LITERATURE CITED

BLAKE, G. R. 1965. Bulk Density. *In* C. A. Black (ed.). Methods of Soil Analysis. Part I. Agronomy 9:374-377.

BREDAKIS, E. J. 1966. Stabilization of Fly Ash by Means of Vegetation and Its Possible use as a Soil Amendment. pp. 1-18. Final Report-Department of Plant and Soil Science. University of Massachusetts, Amherst, Massachusetts.

ENGLE, C. F. and J. P. CAPP. 1967. Fly Ash: New Hope for Strip Spoil? West Va. Agri. Exp. Sta. Bull. 544:1-4.

HAISE, H. R., W. W. DONNON, J. T. PHELAN, L. F. LAWHON and D. G. SHOCKLEY. 1956. The Use of Cylinder Infiltrometers to Determine the Intake Characteristics of Irrigated Soils. USDA Agri. Res. Ser. - Soil Conserv. Ser. 41-7:1-10.

HOLLIDAY, R., D. R. HODGSON and W. N. TOWNSEND. 1958. Plant Growth on Fly Ash. Nature 181: 1079-1080.

JAMISON, V. C. 1953. Changes in Air-Water Relationships Due to Structural Improvement of Soils. Soil Sci. 76:143-151.

KIJNE, J. W. 1967. Influence of Soil Conditioners on Infiltration and Water Movement in Soils. Soil Sci. Soc. Amer. Proc. 31:8-13.

SALTER, P. J. and J. B. WILLIAMS. 1967. Effect of Pulverized Fuel Ash on the Moisture Characteristics of Soils. Nature. 213:1157-1158

EFFECTS OF OFF-ROAD VEHICLES ON THE GEOMORPHOLOGY OF DUNES IN CAPE COD NATIONAL SEASHORE[1]

Stephen P. Leatherman[2]

INTRODUCTION

The dune system in two contrasting areas within the Seashore are being studied to determine areas where vehicular traffic may cause significant environmental change. Provincetown Peninsula and Nauset Spit are both coastal features, created from the material carried by longshore currents from the eroding glacial cliffs (Figure 1). These areas began to build 6,000 years B.P. (before present), when the rising sea first allowed wave activity to focus on the glacial deposits. The shoreline at Race Point in the Provincelands has continued to prograde since this time while at Nauset Spit the beach is quite narrow and the barrier dunes are scarped on their seaward face.

THE PROVINCELANDS

The Provincelands were formed by spit accretion as evidenced by a series of dune ridges, interpreted to represent the shoreline position at particular (earlier) times. These dune ridges have been devegetated largely through human activity. Past neglect can be traced to Pilgrim times in the 1800's when the forests that covered the dunes were felled and horse-drawn carts were used in this area (McCaffrey 1973). The source of sand for the large parabolic dunes is believed to have been derived from partial destruction of these vegetated dune systems. These migrating dunes are burying unique ecosystems, including a beech forest, and threatening to close the main route to Provincetown.

Introduction of the off-road vehicle (ORV) has greatly accelerated the devegetation of this area. The vehicles can quickly destroy the dune grasses (Godfrey 1975), and a blow-out develops. Dune notches and general dune line truncation results (Figure 2); the magnitude of sand loss depending upon the orientation of the cut to the prevailing wind directions. Thus vehicles are rapidly causing an alteration of the shape of the dunes. These changes can be visually detected upon site visit and interpreted from an examination of historical aerial photography. Also, there is a change in relief since the dune crest is significantly lowered. A fundamental question involves the amount of sand displacement downslope, and the experimental approach was adopted in order to quantify this factor.

EXPERIMENTAL APPROACH

A dyed sand technique was implemented to determine the amount of sediment movement as the result of a single pass of a vehicle over a sloped dune. The methodology as devised by Niedoroda and Limeburner (1975) will be briefly reviewed due to its general application for other studies.

Sand to be used as the tracer was taken from the dune field area in order to minimize grain size differences and related effects. There are several ways to coat individual sand grains. A rapid technique is to use fast-drying (red or bright-colored) spray paint. Petrol and printers ink can be mixed in various proportions and then the sand to be dyed added to this solution. In some cases it is desirable to follow the pathways of various grain size ranges, and several colors can be used. For ready examination of the amount of tracer in the sand sample, fluorescent spray paint should be used as described by Williams et al. (1975). Clumped particles should be mechanically disaggregated.

Once the dyed sand was prepared, it was inserted as a strip of sand into the dune face by using a metal box. This rectangular box (with no top or bottom) was hammered into the sand surface (Figure 3A). The sand contained within the box was excavated and replaced with the tracer. The box was removed slowly so that a sharply defined plane of tracer sand was left in the surrounding undisturbed sediment (Figure 3D).

A vehicle is then driven over the strip of dyed sand, and the surface displacement of the tracer was measured (Figure 3E and F). The amount of displacement is quantified by superimposing a gridded, transparent plexiglas sheet over the displaced sand. The amount of sediment movement was then measured at every 5 cm with depth until a point of no displacement was reached (Figure 3H). The total volume of sediment transport was determined by separating the tracer from the surrounding material.

Variables that will affect sand movement include: (1) slope of dune, (2) direction of vehicle motion relative to slope, (3) tire inflation, (4) vehicle speed, (5) sand compaction, and (6) wetness of sand. These parameters were recorded for each test, and Table 1 is a listing of the raw data collected for a series of these tests. The nature of the data lends itself to a statistical treatment. Preliminary analysis by regression indicated that the dune slope angle and tire pressure were the two most significant variables. There was a greater amount of downslope sediment transport with increasing slope. Lower tire pressures resulted in less sand disturbance. These results are not surprising, but quantification was previously lacking.

From this analysis it is clear that sand roads should be re-routed in order to avoid steep slopes. Swales, which are interdunal areas, and low dunes should be selected for possible trails. The tire pressure for an off-road vehicle should be set between 10 and 15 pounds per square inch (psi), depending upon sand conditions and tire tread characteristics. Finally, it is of interest to predict the level of traffic necessary to significantly lower the relief of a dune. Extrapolation of the data gathered may yield an order of magnitude value, but this task will not be undertaken until all data sets have been assimilated.

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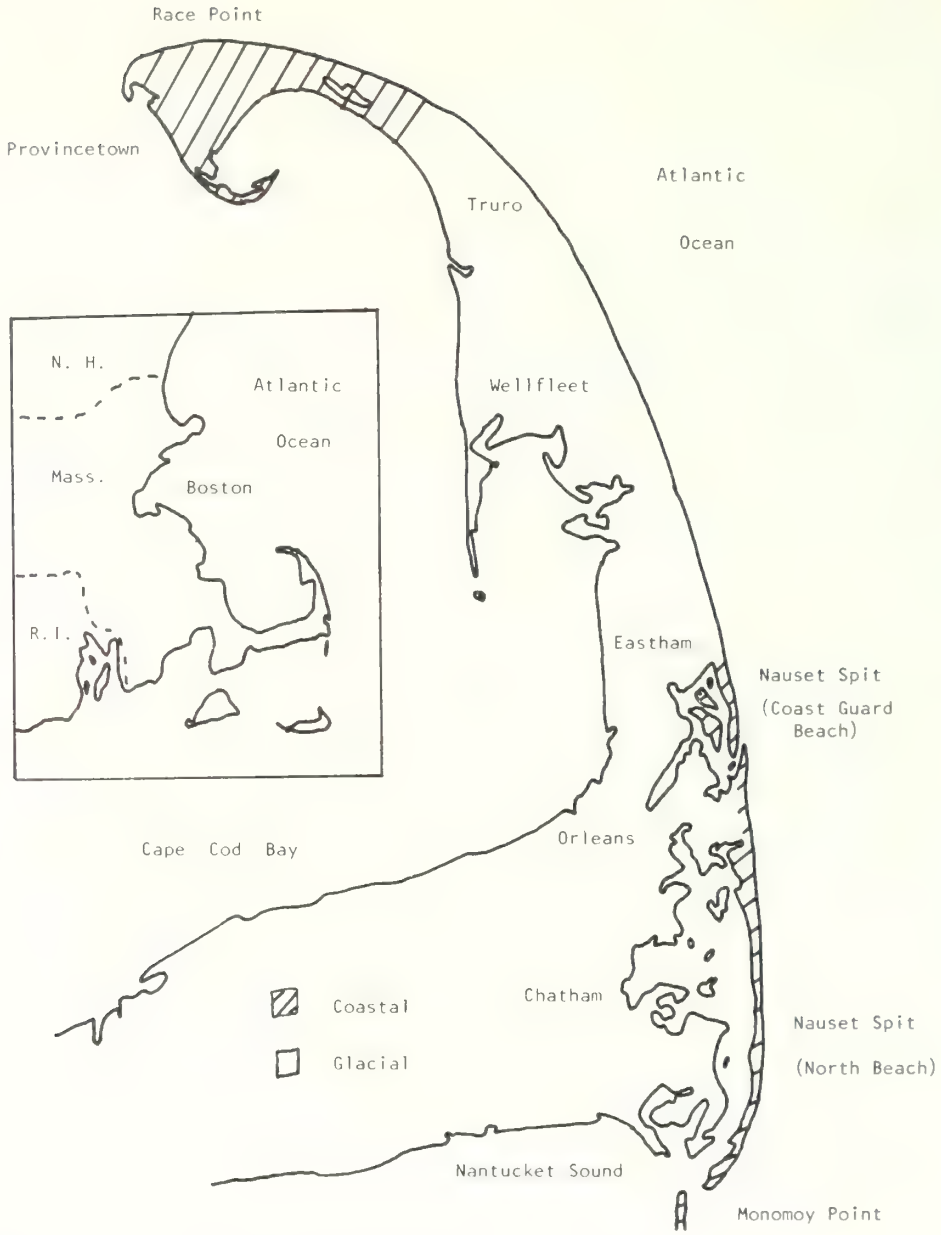

FIGURE 1. The Outer Cape from Race Point to Monomoy Point.

These experiments were also completed for vehicles other than our standard pickup truck since weight and body size differences could be significant. It was necessary to evaluate all types of vehicles, i.e., jeeps, trucks and campers, used by the recreationalists in the Seashore. Also, the natural movement of the sand was compared to vehicle displacement. The rate of sand movement by the wind was determined on site by sand traps. These data will be used to select areas where ORV activity will result in the least amount of disturbance and to determine the level of usage (carrying capacity).

Nauset Spit

Coast Guard Beach parking lot in Eastham marks the end of the eroding glacial material and the beginning of Nauset Spit. The National Park Service built this parking lot in 1964, but rampant shoreline recession threatens to close off this area (Figure 4). The sand derived from the eroding cliffs of Eastham and Wellfleet has served to create and nourish Nauset Spit and Monomoy Island.

The northern portion of the Spit is under th jurisdiction of the National Park Service, and the remainder of the Spit is mandated for incor poration into the National Seashore. Barren washover flats and smaller washover fans are pr sent along the length of the Spit. Overwash ha been shown to be a significant process on some of the mid-Atlantic and southeastern barrier is lands, but no data exists at present to define its role in the Cape Cod area.

It is possible that frequent overwashes are not the normal course of events and that the pr sent condition is the result of off-road vehicl Vehicular passes through the dunes can result i devegetation and blowouts, and these pathways c serve as overwash channels during storm condi- tions. Also, the continued perturbation of the sand surface by these vehicles prevents reveget tion. The establishment of American beach gras may lead to the formation of dunes, reducing th frequency of overwash occurrence.

A sediment budget approach may show that ove wash processes result in the accelerated erosio

FIGURE 2. Devegetation and truncation of the Provinceland dunes.

of Coast Guard Beach parking lot. The accretion of sediment on the barrier flats and bay necessitates a loss of this material from the beach and shoreface. On the other hand, it is possible that frequent overwash activity might be desirable. The new sediment delivered to the bayshore can act as a substrate for marsh development and the surge water may be important in terms of flushing of the marsh-bay system.

FIELD PROGRAM

Eleven washover fans along the length of the Spit have been selected for study. Several of these areas were planted with American beach grass by the Massachusetts Beach Buggy Association (MBBA) in April 1976 under my direction. Figure 5 shows one of the closed washover fans that have been covered with a portion of the 16,000 grass plants. These areas are being surveyed in order to determine the effectiveness of using grasses to revegetate barren flats and/or build dunes. The MBBA feels committed to this program of grass planting since it is commonly believed that these areas are the result of ORV activity and therefore are not natural. In order to address this question, several of the washover fans have been closed off to serve as controls. In other areas the present access is allowed to continue. This portion of the study will not answer the question of the origin of these barren flats but will determine if ORV impact is responsible for their lack of revegetation.

The site descriptions are given in Table 2. These sites are numbered from South to North in the order that they were established. At each site, there are four to five survey lines transecting each of the features, perpendicular to the shoreline with the survey lines extending to the water line. These areas will be surveyed on a quarterly basis for at least the next three years in order to determine revegetation patterns and record elevation changes (dune development). The purpose of this extensive project is to evaluate the relative roles of overwash and dune building and determine the impact of vehicles on these processes.

CONCLUSION

Off-road vehicles can directly result in reduction of dune relief. In the Provincelands, dunes of over 150 feet in height are largely unprotected from this type of activity. For Nauset Beach, devegetation and subsequent deflation can result in artificial breaks in the dune line. During storm conditions these breaches serve as overwash channels to funnel sediment to the marshes and bay waters. The American dune grass, which colonizes the dunes in both areas, is very susceptible to ORV impact. These grasses have adapted to the harsh physical stresses inherent in their environment, but have not evolved with vehicular stress. These studies should determine if substantial long-term disruption of natural geomorphic processes occurs as the result of off-road vehicles in the coastal system.

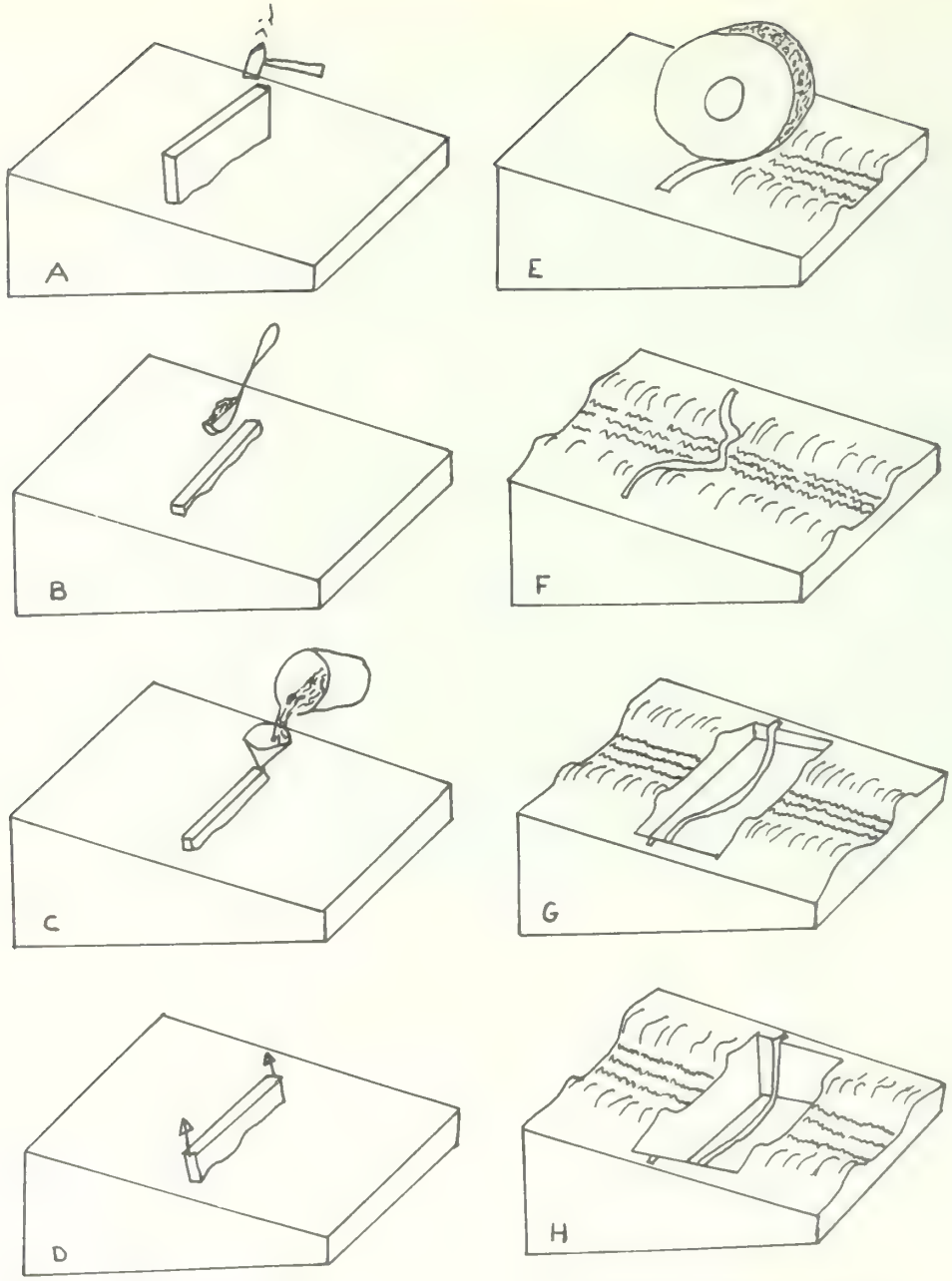

FIGURE 3. Tracer technique for determining downslope sand displacement (Niedoroda and Limeburner 1975).

REFERENCES

GODFREY, P. J., J. BRODHEAD, H. WALKER, J. GILLIGAN and A. DAVIS. 1975. Ecological effects of off-road vehicles in Cape Cod National Seashore, Massachusetts, Preliminary Report, National Park Service, Cooperative Research Unit, University of Massachusetts. 65 pp.

LEATHERMAN, S. P. in preparation. The geomorphologic effects of off-road vehicles in Cape Cod National Seashore, Final Report, National Park Service, Cooperative Research Unit, University of Massachusetts.

MCCAFFERY, C. 1973. An ecological study of t Provincelands, unpublished report, Universi of Massachusetts.

NIEDORODA, A. W. and R. LIMEBURNER. 1975. A preliminary report on the geomorphic effect of recreational vehicles on coastal systems National Park Service, Cooperative Research Unit, University of Massachusetts. 48 pp.

WILLIAMS, A. T., S. P. LEATHERMAN and J. S. FI ER. 1976. Particle size-velocity relation ships for swash sand transport at Cape Hatteras, North Carolina, Southeastern Geology V. 17, p. 231-242.

FIGURE 4. Destruction of Coast Guard Beach parking lot by erosion.

FIGURE 5. Washover breach planted with American beach grass.

TABLE 1. Data from dyed sand experiments.

Volume Transported (cc)	Slope Angle	Angle of Approach	Tire Pressure (psi)	Speed (mph)	Compaction Coefficient (tsi)	Moisture Index (% weight)
1480	7	0	15	1.1	0.0	0.00176
7100	11	0	15	0.1	0.0	0.00339
310	11	0	10	0.6	0.5	0.00170
7100	11	0	12	0.1	0.5	0.00203
350	11	0	12	1.0	0.5	0.00355
1430	8	0	11	0.3	0.2	0.00355
3570	8	0	11	0.3	0.6	0.00646
240	5	0	12	0.5	0.8	0.00324
130	4	0	12	0.7	0.7	0.00191
20	1	0	12	0.7	0.9	0.00130
90	3	0	12	0.5	0.1	0.00367
250	4	0	12	0.1	1.0	0.00424
50	2	0	12	1.9	1.1	0.00185
3130	9	35	12	0.3	1.0	0.00391
525	7	40	12	1.3	0.7	0.00276
175	8	35	10	0.5	0.5	0.00261
95	5	22	10	0.3	1.0	0.00384
175	5	17	10	2.0	0.6	0.00375
1780	7	37	11	0.5	0.5	0.00235
470	5	19	11	0.6	1.0	0.00141
1940	8	0	10	0.7	1.7	0.03100
1660	6	10	10	1.7	0.7	0.03636
360	4	45	11	1.4	0.7	0.02000
2775	7	55	11	0.5	0.5	0.01971
160	7	40	11	1.2	0.0	0.00629
1060	6	32	12	0.1	0.7	0.00670
710	6	35	12	0.3	0.0	0.00670
325	3	45	12	0.3	0.0	0.00400
3795	11	40	12	0.1	0.2	0.01400
7920	10	50	12	0.1	0.6	0.01922
110	4	49	12	0.6	0.9	0.00266
1075	5	50	12	1.1	0.1	0.00241
2300	6	47	12	0.1	0.2	0.00190
1280	8	35	12	0.1	0.0	0.00188
1000	5	42	12	0.1	0.0	0.00633
310	3	0	12	0.6	0.0	0.00131

(UMass - NPS CRU, 1975).

TABLE 2. Washover sites on Nauset Spit

Site	Remarks
1	planted with American beach grass; area is closed
2	1/2 of fan is fenced off for natural vegetation recovery, 1/2 of fan is open for impact
3	planted and closed
4	closed for natural recovery
5	closed for natural recovery
6	open for impact
7	planted and closed
8	1/2 of fan open to impact 1/2 of fan planted and closed
9	closed for natural recovery
10	open for impact (flats at Coast Guard Beach)
11	closed for natural recovery (fan at Coast Guard Beach)

ASPEN UTILIZATION BY LARGE HERBIVORES IN ROCKY MOUNTAIN NATIONAL PARK AND ITS IMPLICATIONS FOR MANAGEMENT

Charles E. Olmsted[1]

Aspen (*Populus tremuloides* Michx.) is the most widely distributed deciduous tree in North America and the only widespread deciduous tree in the Rocky Mountains (Greene 1971). Within National Park Service administered areas, aspen is valuable as an aesthetic component of the landscape and as a forage plant that produces browse for big game animals. It is also an integral part of the pristine ecosystems that the Park Service attempts to maintain (Houston 1971). The deterioration and lack of regeneration of aspen within Park Service Administered areas (notably Rocky Mountain National Park, Grand Teton National Park and Yellowstone National Park) has been discussed in the literature for the last 30-40 years. Excessive utilization by large herbivores, primarily elk (*Cervus canadensis*) and mule deer (*Odocoileus hemionius*) was generally considered to be the controlling factor leading to the decline in aspen. Packard (1942) discussed aspects of the aspen-herbivore interaction at the lower elevations in Rocky Mountain National Park and predicted the decline of the aspen.

More recently, Houston (1973) and Gruell and Loope (1974), working in the Yellowstone-Grand Teton area, have suggested that fire suppression has had a significant influence on aspen reproduction and is primarily responsible for the decline in the aspen stand type. Aspen occurs as climax vegetation (Marr 1961; Reed 1971) as well as successional vegetation and can maintain itself as a persistent type in the absence of coniferous invasion and subsequent shading. A healthy aspen clone can reestablish itself by means of root suckers following a fire more rapidly than conifers can invade by seed. The occurrence of intermittent fires would permit the development of large expanses of aspen vegetation of a successional type. Fire suppression has undoubtedly decreased the areal extent of the aspen stand type and focused herbivore use on the areas where aspen could maintain itself as a persistent type without periodic fire.

The area of study reported on in this paper is a portion of the elk winter range on the eastern side of Rocky Mountain National Park. The range is composed of a series of east-west trending ridges and moraines with intervening grassy parks and meadows. The range is bordered on the north, west, and south by mountain ridges sufficiently high to form a winter barrier to elk migration and on the east by the expanding development of the community of Estes Park.

The utilization of aspen on this range appears to be equal to or more severe than that reported from the Grand Teton area. The utilization is of two types, bark-stripping (barking) and twig browsing, and occurs primarily during the winter months. Virtually all mature trees on the range are barked to a height of approximately two meters. This barking probably occurred over a period of time in the past and the development of scar tissue renders these trunks immune to further ungulate herbivory. The following example indicates the demand for the bark resource that exists within the Park today. A living, dormant, mature aspen tree (approximately 20 m tall with a D.B.H. of 28 cm) was windthrown in early April 1976, within the winter range area. By late May, all of the reachable, unscarred bark had been consumed. The only bark remaining was in the following locations: at the bases of branches (areas too constricted to permit stripping); in a strip 4-5 cm wide on the underside of the trunk (within 30 cm of the ground) and the 2 m long band of previously developed scar tissue at the base of the trunk. The second type of utilization is the browsing of the woody twigs of the previous summer's growth. This type of use occurs repeatedly on the same sprout. On vigorous sprouts it is possible to trace this type of use over several years. The browsing history develops through the following pattern: a woody shoot develops during the summer and is browsed back during the winter; during the second summer the lateral buds of the shoot stub develop into new woody shoots and are in turn browsed back during the following winter; the third summer the lateral buds of the second year stubs develop and are subsequently browsed the following winter. The relative vigor of the shoots produced each year declines for a given sprout as this type of utilization continues.

Within the Rocky Mountains, aspen reproduction is almost entirely dependent on the vegetative propagation of suckers from roots. Although viable seed are produced, the current climatic regime is apparently inimical to seedling establishment. The majority of naturally occurring aspen seedlings that were reported have been associated with subsurface springs or the shore of a drawndown reservoir (Every and Wiens 1971; Larson 1944). Aspen occurs primarily in clonal form and the maintenance of the clone depends upon the replacement of senescent trees by developing vegetative ramets. Within the study area this form of replacement is virtually nonexistent and most stands are declining. The most notable exceptions to this are located within exclosures that prevent utilization by large herbivores.

The season's woody growth of twigs on developing suckers can be looked at as a direct indication of the stand's ability to replace dying trees. The fate of this yearly cohort of twigs will predict future stand development.

METHODS

Thirteen permanent transects were established in aspen stands on the lower eastern drainages of Rocky Mountain National Park. The transects were oriented perpendicular to and crossed the boundaries of stand development where such boundaries were evident. The transects extended from the margin to the apparent center of each stand. When stand boundaries were indistinct, the transect was oriented parallel to slope contour and randomly, but well within the stand. The transects were each 1 m wide by 2 m high and ranged in length from 20 to 120 m. In an effort to minimize interference with normal herbivore behavior patterns, the transects were marked only by small metal rods at 10 to 30 m intervals. Trees within the transect were located by a coordinate system and the individual twigs on each tree were named on the basis of a hierarchical branching system.

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The winter history of 7242 twigs of the previous season's growth was followed. The transects were resampled at monthly intervals from October 1975 to May 1976. Condition, basal diameter, upper diameter, total length, nonviable length, and number of buds were recorded for each twig on each visit. Twig volume production per stand and the rate of decline of twig volume over time were calculated from these data. The productivity and utilization data were calculated on a volume rather than a weight basis in order to avoid destructive sampling of an already limited resource.

RESULTS AND DISCUSSION

Figure 1a displays the variation in productivity within the sampled stands. The data are adjusted to cubic centimeters per 100 square meters for comparison purposes because the area enclosed by the transects varied depending on stand geometry. Figure 1b displays the variation in seasonal woody growth remaining following the winter browsing interval. The data are adjusted to per cent of initial productivity remaining (inverse of utilization) in order to facilitate interstand comparison. There is no clear relationship between the amount of production and the per cent reduction over time. The most productive stand, M, also had the greatest reduction in twig volume (79%) but the least productive stand, A, had the next greatest reduction in twig volume (71%). Stand H was located within an exclosure and served as a control stand. Stand H suffered a 3.8% loss in twig volume, primarily due to the abscission of spur shoots. The abscission loss within the control stand was probably higher than that in any of the other stands due to apparently intense competition between the developing ramets. There was no loss of twig volume through browsing or breakage within the exclosure.

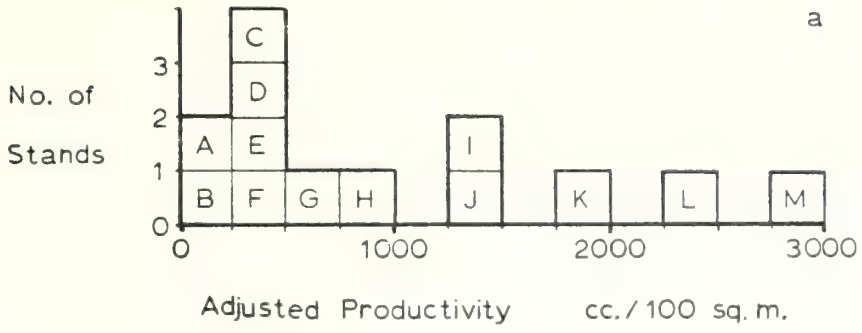
Several recurrent patterns of utilization over time are apparent in the data. The examples given are representative of the differing use patterns. Figure 2 demonstrates a rotated sigmoid curve pattern. This pattern of use is more common on the higher elevation stands within the study area and appears to be correlated with midwinter snow accumulation. The altitudinal variation is relatively small within the study area (approximately 150 m) and the 1975-6 winter was a mild one. There is very little evidence of browsing utilization in an aspen stand located in lower Hidden Valley, which is approximately 200 m higher than the elevations covered by the study area. It is probable that the increase in elevation leads to a concomitant increase in snow accumulation that serves to protect the aspen stand from ungulate herbivory during the winter browsing season. The implication that follows from the above evidence is that during more severe winters with increased snow accumulation, the upper limit of the useful winter range is very close to the Park boundary. This will tend to concentrate browse utilization to an even greater extent.

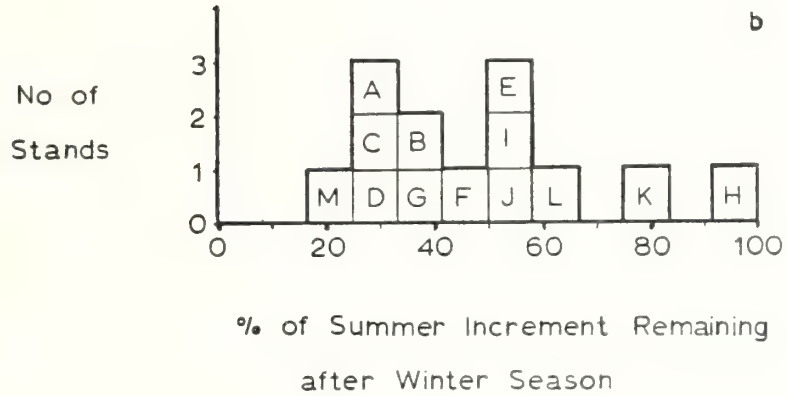
The second pattern that appears in the data (see Figure 3) is a hyperbolic curve with high initial use rates followed by a decline in utilization. This may reflect a level at which the resource becomes unavailable to the herbivores. This unavailability may be due to either scarcity or location of the resource. In the example in Figure 3, only 37.4 cc of twig volume remained at the end of the winter browsing period within a sample area of 60 square meters. With reference to the unavailability of the resource, the sample height of 2 meters may not have accurately reflected herbivore use patterns. This height was selected on the basis of the bark scarring on the trunks. In one sample site, the transect was placed in a stand from which a browsing exclosure had been recently removed (1972). The smaller trees in this stand had developed during the period of protection and had branches along the length of their trunks. The seasonal twig growth was extensively browsed in the area between the ground and a height of approximately 1.5 meters but the twigs in the upper quarter of the sample zone were left largely intact. Most of these trees were also barked at a height of 1 to 1.5 meters. Subsequent examination later in the year indicated that the trees were killed by girdling at the point at which they were barked and that the twigs remaining above the barked trunk were no longer viable.

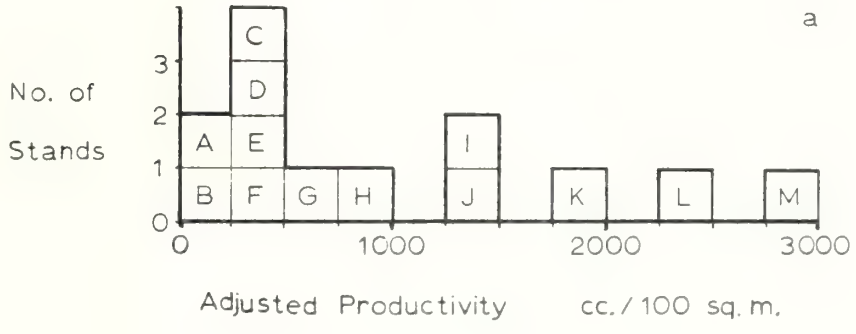
Figure 4 shows the linear pressure effects of continual browsing in the lower elevation stands within the study area. This sort of linear pressure is exerted on different stands to varying degrees. In several cases at high rates of utilization in these stands the same twig was browsed three or four times during the course of the winter. Several factors may be responsible for the variation in use rates shown here and work is in progress to attempt to find the causal agents. The following factors appear to merit consideration: proximity to roads (open in winter) and other areas of potential human activity; clonal variation in flavor and/or nutritive value; and relative ease of movement within the stand (stand density, stem spacing, windthrows, etc.).

The initiation of a root sucker can be considered an energy investment by the clone as its development is dependent on clonal root carbohydrate until the shoot becomes photosynthetically self supporting. The use of carbohydrate reserves for leaf manufacture is readily made up for by subsequent photosynthesis, but woody tissue development constitutes an energy investment for future growth. If this woody tissue is removed at a rate in excess of the rate at which the energy required to manufacture it is fixed by photosynthesis, then the carbohydrate reserves in the roots will be depleted and the stand will decline. Conversely, if the energy fixed by photosynthesis is in excess of that required to replace woody tissue loss, then the root reserves will be built up and the stand will be maintained or increase.

Figure 5 is a comparison of data collected by Stevens (pers. comm.) on aspen density in 1970 and 1973 in four stands within the study area with the 1975-6 browsing transect data for the same stands. The data are presented on a per cent change in density and per cent seasonal twig growth remaining basis for ease of comparison. The relationship between the measurements is quite close and seems to indicate that stand maintenance requires that at least 70 per cent of the twig volume produced in a summer growing season remain unbrowsed. This estimate is based on three points because the data from the fourth stand are not comparable. This stand (point A) was the stand discussed earlier from which the exclosure was removed in 1972. The density transect was located outside the former position of the fence but the browsing transect was placed inside the formerly protected area. As mentioned previously, the twigs in the upper portion of the sample area were not substantially browsed but the trunks of several of the smaller trees were girdled by barking. The twig volume reduction figure in point A is based on direct removal of twig volume by browsing. If the twig volume lost through mortality due to trunk girdling within the sample area is also considered, then the







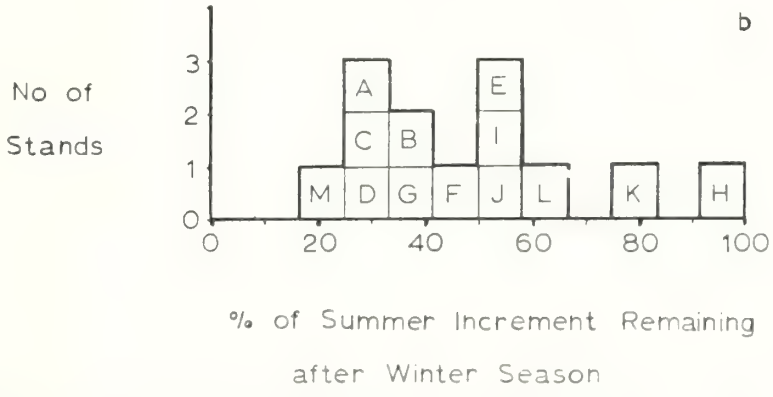


FIGURE 1. Productivity (a) and utilization (b) as measured by twig volume. Letters indicate individual stands.

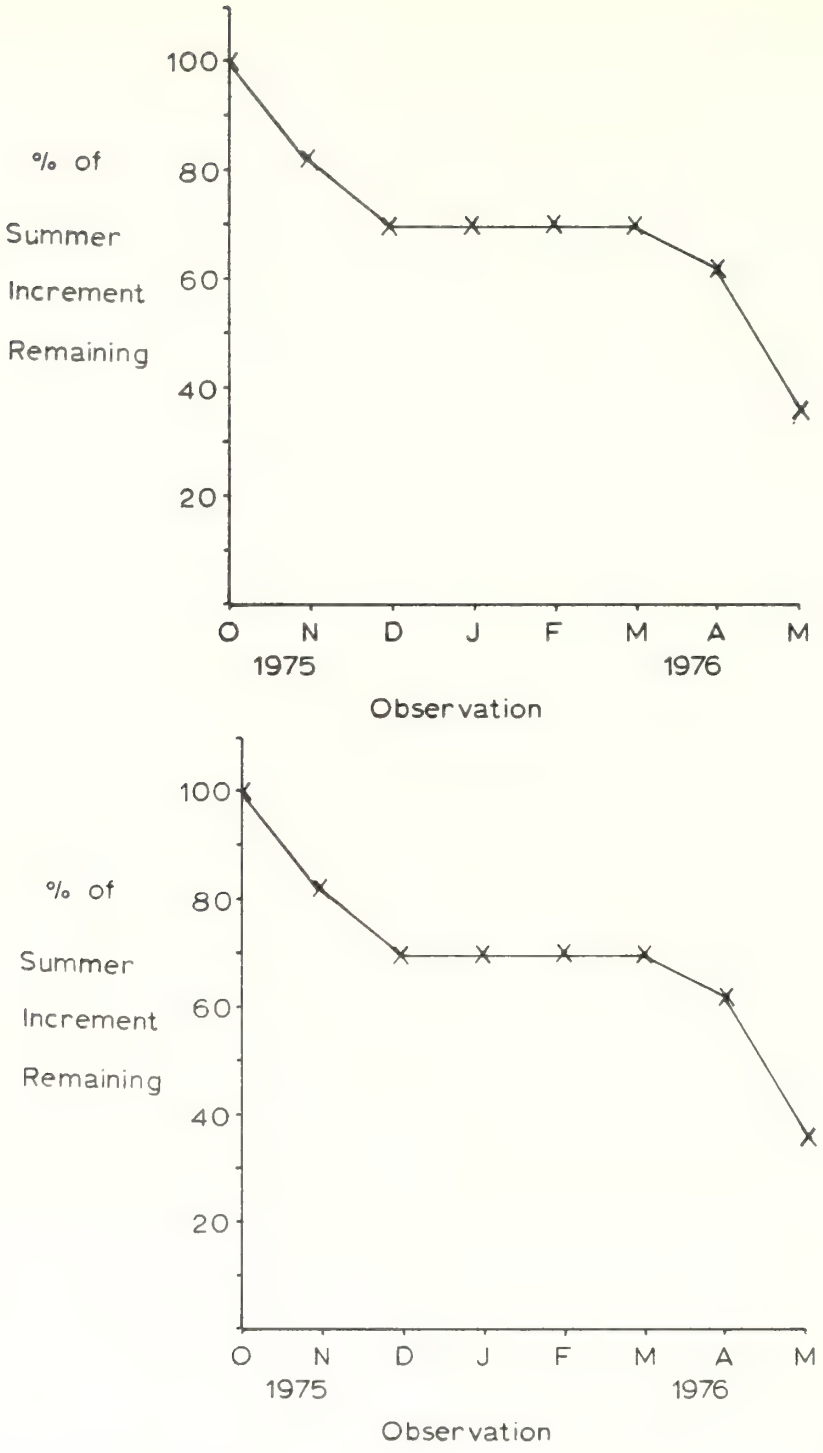


FIGURE 2. Twig volume loss as a function of time. Data from Beaver Meadows--Deer Ridge, elev. 2652 m adjusted productivity = 527.5 cc/100 sq. m.)

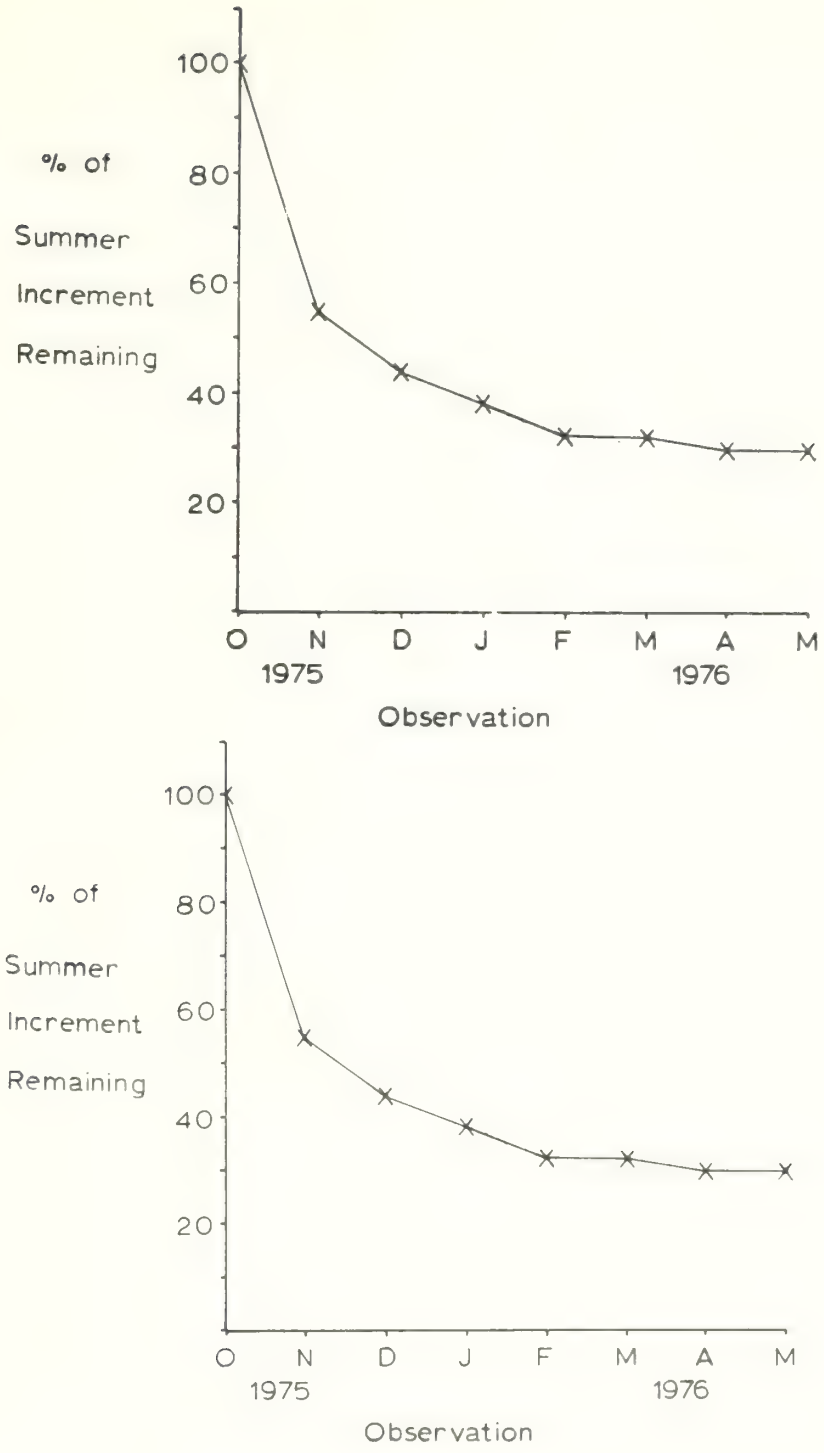


FIGURE 3. Twig volume loss as a function of time. Data from Hondius Park. elev. 2458 m; adjusted productivity = 205.1 cc/ 100 sq. m.)

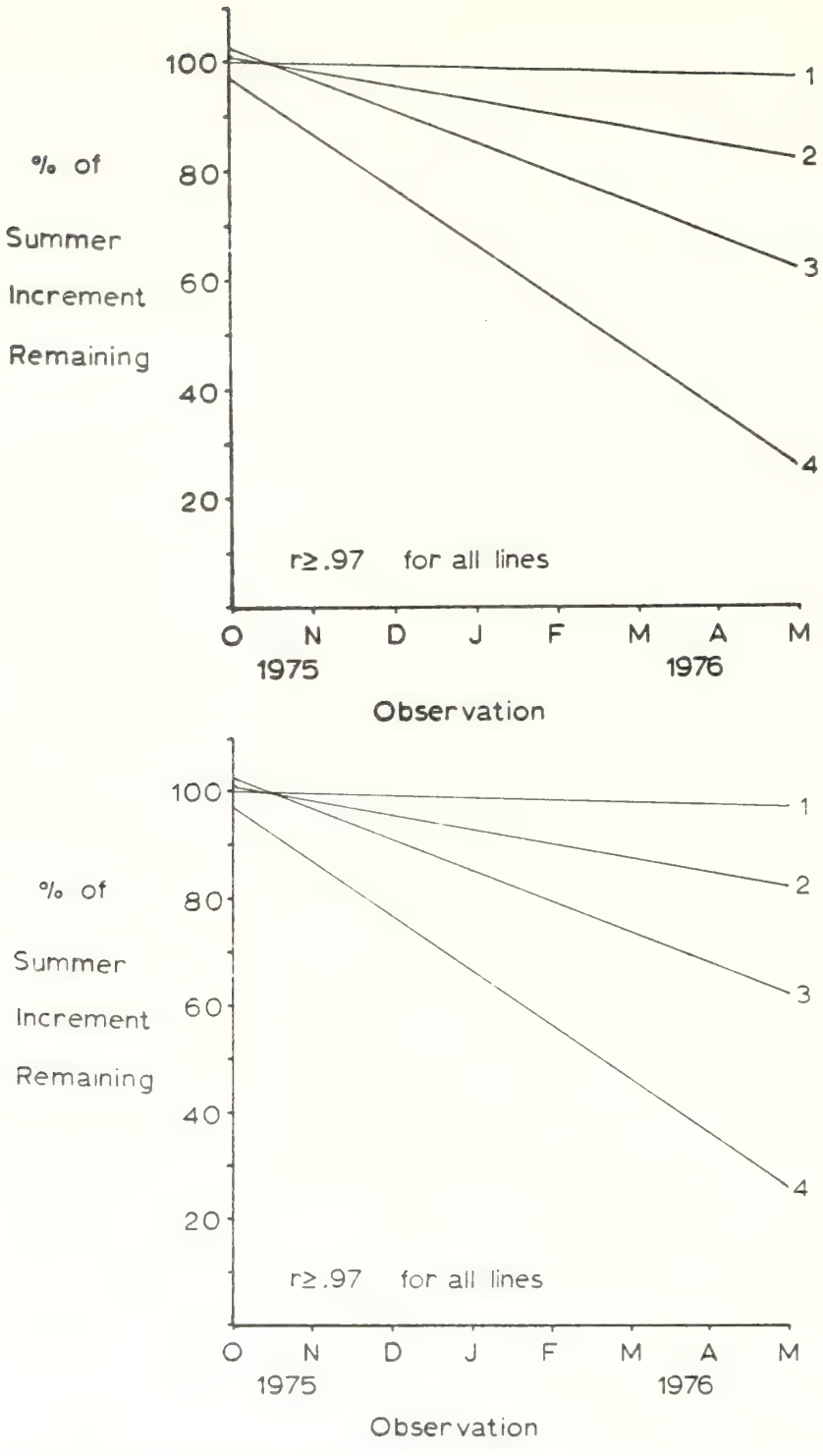


FIGURE 4. Comparison of twig volume loss rates of lower elevation stands. Rates are a direct transfer of the best-fit linear regression for each stand: Beaver Meadows exclosure (1); Moraine Park (2); Lower Beaver Meadows (3); Upper Beaver Meadows (4).

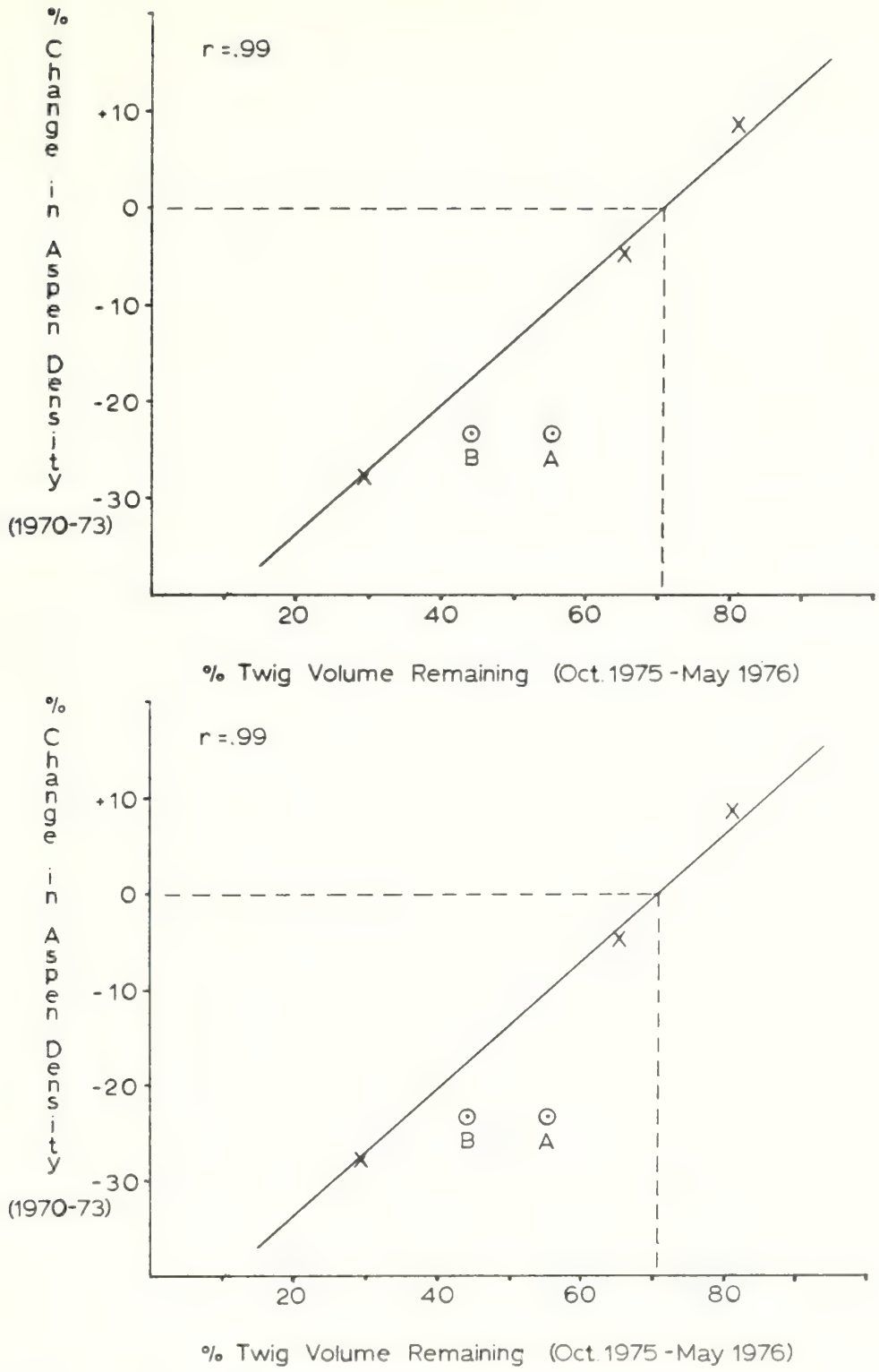


FIGURE 5. Comparison of change in aspen density over time with browse utilization for one season. Raw data for aspen density from D. Stevens.

result for this stand is shifted to point B. It appears likely that the utilization of this stand will fall in line with that of the other stands as the effect of the recent period of protection is moderated over time.

Only two of the thirteen stands examined within the study area retained volumes of seasonal twig growth sufficiently large to indicate clone maintenance. The first of these was the control stand within the browsing exclosure. The second stand received the lowest utilization (19.7%) and is increasing in density (stems/hectare) but is not developing mature trees. The level of utilization is such that while root energy reserves are being maintained or increased, the developing sprouts are being pruned by browsing into large bushes. This permits adequate photosynthesis to maintain the clone but does not lead to the development of mature trees to replace those that become senescent or die of other causes. This clone may have the ability to survive the current levels of browsing utilization within the study area.

The levels of utilization of aspen in the other stands examined within the study area leads to the conclusion that net root energy reserves of the clones are decreasing and the stands will eventually disappear. Seedling establishment is quite rare under the current climatic patterns (Baker 1925; Every and Wiens 1971) and the natural replacement of these stands is unlikely under the present climate and/or browsing levels. Cottam (1954) has suggested that the widespread distribution of aspen may date from the pluvial intervals associated with the Pleistocene glaciations. The clones established then may have maintained themselves by vegetative means since that time. The decline and potential disappearance of these aspen stands on the winter range within Park boundaries does not seem consonant with the maintenance of pristine ecosystems as discussed by Houston (1971).

The implications of the research discussed above in combination with evidence presented by Sampson (1919) raises a substantial concern about the use of fire as a management tool. The role of fire in natural ecosystems and its importance in the maintenance of aspen stands has been extensively discussed (Daubenmire 1943; Houston 1973; Loope and Gruell 1973; Gruell and Loope 1974). Fire suppression has undoubtedly had a significant effect on the status of successional aspen stands. More recently, prescribed burning in addition to naturally occurring fires has been suggested as a means to stimulate decadent aspen stands (Gruell and Loope 1974; Stevens pers. comm.; Kegley pers. comm.). The immediate effects of a hot fire will be the mortality of the above ground portion of the aspen clone. This will prevent further energy input into the clonal root energy reserves. The vigor and abundance of the reproductive suckering will be dependent on the existing energy reserves within the root system and the survival of these suckers will be dependent on the ambient browsing pressure in the area. If the root reserves are low or the browsing pressure is high then the probability of reestablishment of the clone is reduced. If both these circumstances prevail then the rapid extinction of the clone is likely to follow. Sampson (1919) investigated the influence of browsing on aspen reproduction following logging by clearcutting (another means of both stimulating suckering and removing energy input into the clonal root network). He found suckering to be vigorous, abundant, and widespread for the two growing seasons following the cutting of a healthy, closed aspen stand. The sprouts produced in each season were extensively browsed back by sheep and cattle. The third growing season, the sprouts were not as abundant, they lacked vigor, and they tended to be scattered in clumps instead of being evenly distributed over the site. If these suckers were also browsed back, no sprouts were produced the following years. The implication of Sampson's work is that the root reserves of a healthy clone will be totally depleted if it is intensively browsed for several years following the destruction of the above ground stems.

The nature of the sucker production that exists in most of the aspen stands on the lower winter range in Rocky Mountain National Park is comparable to that described by Sampson for the third season after cutting and browsing. The reproduction is not abundant, is not vigorous, and it occurs in scattered clumps. This reproduction is probably supported by the remaining root carbohydrate energy reserves of recently fallen trees and the continued energy input of the remaining senescent trees. If the standing trees are killed by fire or other means, then stand continuance will be dependent on an already depleted root system. If this occurs under the present levels of browsing utilization, then the rapid eradication of the clone will probably ensue.

CONCLUSIONS

Two conclusions may be drawn from the material presented here: the level of browsing utilization compatible with stand maintenance is relatively low (approximately 30%) and that the use of fire to stimulate aspen stands may have the opposite effect and lead to their rapid elimination. Both of these conclusions need to be investigated further. A small prescribed burn was initiated in November 1976 in a decadent, persistent aspen stand within the study area. The fire may have been too fast and cool to have killed the majority of the mature trees. The burn included half of one of the browsing transects and will be monitored in the future. A small portion of the stand was left unburned to act as a clone reservoir in the event that the rest of the stand is eliminated.

The potential consequences of the application of fire to weakened persistent aspen stands indicate that the use of fire as a management tool should be researched thoroughly and approached cautiously. The use of fire may be highly effective in areas in which aspen is successional to conifers. In these areas fire should probably be applied on a scale which will reduce relative browsing pressure to levels below the critical level for stand maintenance. Large scale fires may accomplish this by in effect diluting the number of herbivores relative to the availability of the resource. In other cases, some means of reducing browsing pressure will have to be found to increase the possibility of successful aspen regeneration. Fencing and/or substantial local herd reductions for an interval both before and after the stimulation is attempted may be necessary, especially in light of the decadent condition of many of the aspen stands.

LITERATURE CITED

BAKER, F. S. 1925. Aspen in the central Rocky Mountain Region. U.S.D.A. Bull. 1291. 46 p.

COTTAM, W. P. 1954. Prevernal leafing of aspen in Utah mountains. J. Arnold Arboretum 35: 239-250.

DAUBENMIRE, R. F. 1943. Vegetation zonation in the Rocky Mountains. Bot. Rev. 9:325-393.

EVERY, A. D. and D. WIENS. 1971. Triploidy in Utah aspen. Madroño 21:138-147.

GREENE, J. G. 1971. Clonal variation in *Populus tremuloides* Michx. on the east slope of the Front Range, Boulder Co., Colorado. Ph.D. thesis, Univ. of Colo. 298 p.

GRUELL, G. E. and L. L. LOOPE. 1974. Relationships among aspen, fire and ungulate browsing in Jackson Hole, Wyoming. U.S.D.A. For. Serv., Intermountain Region Publicaton sponsored by U.S.D.I. Park Serv. grant. 33 p.

HOUSTON, D. B. 1971. Ecosystems of National Parks. Sci. 172:648-651.

_____. 1973. Wildfires in northern Yellowstone National Park. Ecol. 54:1111-1117.

KEIGLEY, R. Rocky Mountain Regional Office, National Park Service, Denver, Colo.

LARSON, G. C. 1944. More on seedlings of western aspen. J. For. 42:452.

LOOPE, L. L. and G. E. GRUELL. 1973. The ecological role of fire in Jackson Hole, northwestern Wyoming. Quat. Res. 3:425-443.

MARR, J. W. 1961. Ecosystems of the east slope of the Front Range in Colorado. Univ. of Colo. Studies, Series in Biol. No. 8. 134 p.

PACKARD, F. M. 1942. Wildlife and aspen in Rocky Mountain National Park, Colorado. Ecol. 23:478-482.

REED, R. M. 1971. Aspen forests of the Wind River Mountains, Wyoming. Amer. Midl. Natur. 86:327-343.

SAMPSON, A. W. 1919. Effect of grazing on aspen reproduction. U.S.D.A. Bull. 741. 29 p.

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LAND USE HABITS AND CHANGES IN VEGETATION ON EASTERN OREGON RANGELANDS: AN HISTORICAL PERSPECTIVE

D. A. Shinn[1]

INTRODUCTION

A prominent goal of the National Park Service is the reintroduction and maintenance of natural processes which existed on parklands prior to European settlement (Leopold et al. 1963). During the past century, the interaction of cultural events and natural processes has altered the landscapes of Lava Beds National Monument and John Day Fossil Beds National Monument, and now this interaction must be altered in order to recreate a vignette of primitive western America.

But reestablishment of a pre-settlement image in any park can only be achieved with a clear understanding of the forces which have moved its particular biotic associations from their pristine to their present condition. And the development of this understanding requires an expanding ecological and historical knowledge of the greater regional landscape within which the park is located. Our national parklands are not isolated ecosystems, now segregated by legislation and by resource distinctions. They cannot be managed independently of the man-nature continuum which has moved with them through time. Integrated ecological programs, developing a coordinated understanding of this dynamic continuum can provide valuable insight in the restorative management of our parklands.

In the present study we have correlated current ecological data with information about the changing human influence on land occasioned by the shift from Native American to European proprietorship. We have outlined the forces involved and have examined their impacts on range vegetation. By developing an ecological history of eastern Oregon based on the forces and impacts studied, we can assess their significance in restorative land management.

RANGELAND ECOLOGY

Current ecological literature reveals many general features common to most semi-arid landscapes. Three are of particular interest in the present study.

First, a strong competitive relationship exists between shrub vegetation and its herbaceous understory. If the growth or reproductive capacity of herbaceous species is inhibited, shrubs prosper. However, if the woody vegetation is damaged or destroyed, herbaceous species grow vigorously and extend their influences. In the present discussion of eastern Oregon rangelands this relationship is characterized by the *Artemisia-Agropyron* association.

Two other general features, grazing and wildfire, are closely associated with this woody-herbaceous competition. In general they have acted reciprocally in the elastic balance of semi-arid ecosystems. Their relationship has been significant in the flux of species distributions in the *Artemisia-Agropyron* association. Though these two forces are inseparable one from the other and from the biotic complex in which they occur, we can say that in a healthy, co-dominant stand, heavy grazing pressure alone would tend to shift the balance toward sagebrush dominance; and fire alone would facilitate a shift toward bunchgrass dominance. The season and degree of influence, and of course, the characteristics of the particular plant assemblages affected, all have a great bearing on community response to fire or grazing pressure (Blackburn and Tueller 1970; Cottam and Stewart 1940; Daubenmire 1940; Harniss and Murray 1973; Humphrey 1953, 1963; Kozlowski and Ahlgren 1974; Moomaw 1957; Sweeney 1968; Wright 1974).

ABORIGINAL ENVIRONMENT

For several thousand years prior to European settlement, eastern Oregon supported a diversity of herbivores--deer, antelope, bighorn sheep, bison, and large populations of small mammals and birds. Through long association the foraging behaviors of these animals were well suited to the life processes of their plant associates (Sauer 1944, 1950).

And this diverse wildlife was prey to a native human population whose behavior and customs were also well suited to the necessities of their environment (Berreman 1937; Cressman 1956; Driver and Massey 1957; Jenning 1968). A review of anthropological, historical and ecological literature has demonstrated that Native American peoples in virtually every geographic region of North America burned their land to achieve specific objectives. Fields and forests were periodically set afire to facilitate hunting, warfare, transportation, food gathering, and to improve natural pasturage (Boardman 1967; Dicken 1976; Humphrey 1953, 1963; Sauer 1944, 1950, 1956; Stewart 1951, 1965).

Of importance here is the fact that fire was used in these ways by aboriginal peoples throughout the Pacific Northwest. We have found 24 references to fire and burned vegetation in the journals of early travelers in the Great Basin region (Farnham 1843; Franchere 1854; Irving 1955; Lewis and Clark 1959; Minto 1900; Ogden 1961, 1971; Townsend 1839; Turner 1873). Sixteen of these explicitly attribute the cause of burning to Native American peoples. In 1852 fire was used by Modoc warriors in the area of Lava Beds National Monument (Turner 1873). Ogden's party, while exploring east-central Oregon saw many fires and passed much land burned by native inhabitants (Ogden 1961, 1971). Bonneville in 1834 was troubled by the smoke and heat of a single fire along his entire route from the mouth of Burnt River to the headwaters of the Umatilla River (Irving 1955).

From this evidence we can see that native cultural burning was a significant feature of the Great Basin environment prior to European settlement and it is reasonable to believe that it had been an environmental standard for thousands of years before it was first mentioned in our literature. Native wildlife grazing and native cultural burning must have shared a truly natural balance when we arrived.

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POST-SETTLEMENT ENVIRONMENT

After early Spanish explorations of North America, this balance was altered by the introduction of horses, but the influence was relatively small and localized (Galbraith and Anderson 1971; Lewis and Clark 1959; Ray 1971). With the influx of European culture during the 17th century, the balance was upset. Grazing pressure on range vegetation was intensified by the introduction of large herds of livestock, their numbers increasing rapidly as immigration continued. By 1860, 65,000 people shared the Oregon landscape with 187,000 cattle and sheep (Galbraith and Anderson 1971). The number of cattle in eastern Oregon increased slowly until about 1940. The elevated rate of increase in numbers of cattle thereafter is associated with a dramatic decrease in numbers of sheep, whose impact on range vegetation was far more severe. This shift from a sheep dominated range economy to one dominated by cattle was accompanied by a livestock industry advance between 1950 and 1955 but the number of sheep and cattle in eastern Oregon was by then far below earlier levels. In 1969 this number was even below that of 1890 and was declining (Figure 1) (U.S. Census 1850-1969; U.S. Census of Agriculture 1925-69).

In the early years of European settlement, use of fire was careless and haphazard (Griffiths 1902). After about the turn of the century stockmen became more concerned about protecting their rangeland and their livestock from fire. This concern was associated with the overall initiative to conserve declining range resources. When Federal agencies began to regulate grazing, suppression of all fires was a standard component of rehabilitation programs. This fire policy has been much too simplified (Agee 1974; Dicken 1976).

Changing land use habits in eastern Oregon during the past 150 years have resulted in a significant shift in the dynamics of rangeland ecosystems. Natural grazing levels and behavior have been replaced by artifically intensified grazing pressure of herbaceous species, and cultural and natural burning pressure on shrub species has been virtually eliminated.

A number of early photographs from east-central Oregon were gathered in which range vegetation was pictured. Each photo-site was relocated and rephotographed during the summer of 1976. Figure 2 is an example of the photo-set comparisons which resulted.

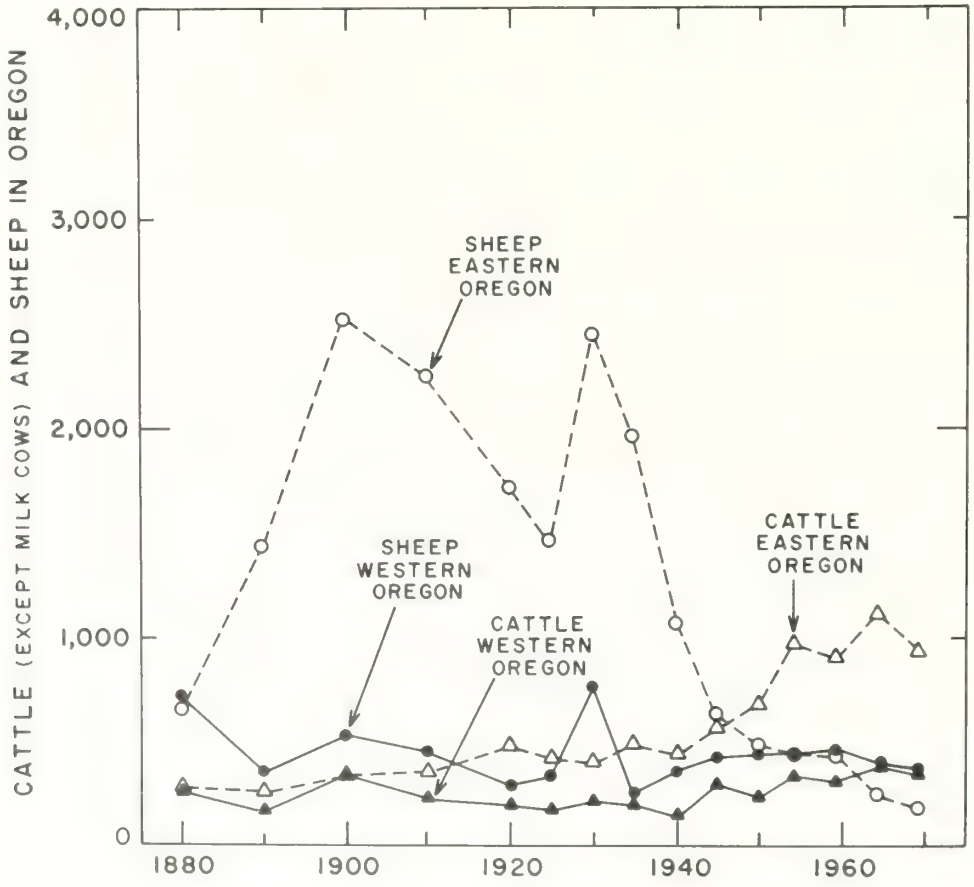

FIGURE 1. Numbers of cattle and sheep in eastern Oregon and in western Oregon from 1880-1969.

The misfortunes of overgrazing were aggravated by a growing misapprehension about fire. Broadcast burning continued, though its aboriginal balance with grazing had already been disturbed, for the habits of many stockmen constituted a destructive misuse of native customs of burning.

Juniperus occidentalis is indigenous to eastern Oregon, and is highly vulnerable to burning. Aboriginally, fire prevented juniper growth on the open range. But when fire was excluded from the *Artemisia-Agropyron* association, juniper populations began to invade open range (Barney and

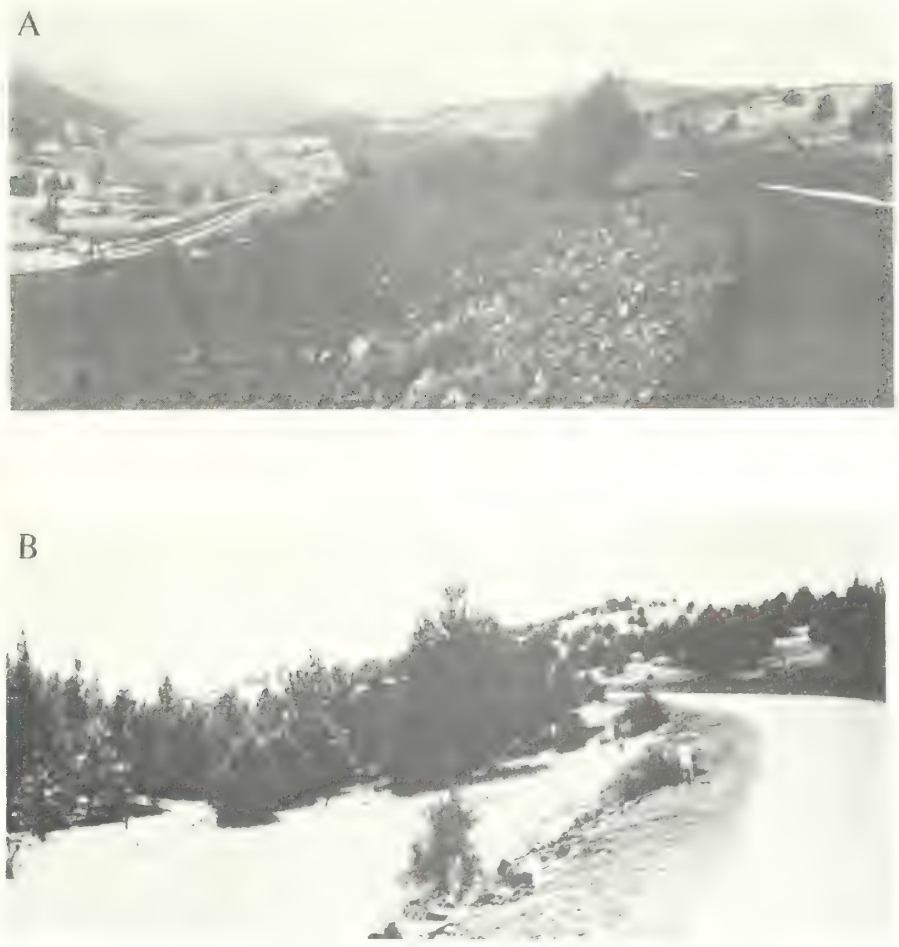

FIGURE 2. (A) An overgrazed livestock driveway on the left reduced to bare soil by the early 1930's. Range vegetation on the right. (B) Heavy juniper invasion of the driveway on the left and of the rangeland on the right. Ponderosa pine advances at extreme left.

Frischknecht 1974; Blackburn and Tueller 1970; Dricoll 1964a; Wright 1974).

Expansion of *Juniperus occidentalis* populations was, therefore, used as an index to the impact of fire exclusion on each photo-site. Average increase of trees per year was calculated for each of 17 photo-sets. Lower average increases per year on sites first photographed in more recent years indicate a reduced rate of juniper invasion as densities increased (Figure 3).

On one site which was photographed in 1920, 1945, 1956, and 1965 (Figure 4), a similar trend is apparent--the rate of density increase in the juniper population has declined in recent years (Figure 5). A closed woodland community is being established.

Fuel accumulations under such circumstances greatly increase the threat of fire. Should a fire occur burning would be intense and its impact on the rangeland would be extreme.

CONCLUSIONS

By summarizing the environmental forces which have acted on eastern Oregon rangelands through time, the process of change in biotic association on parklands may be outlined.

Before man entered the Pacific Northwest environment, grazing pressure was exerted by a diversity of wildlife species; lightning and seismic activity shared responsibility for the influence of wildfires.

As aboriginal man moved onto the North American continent, cultural burning began to intensify the environmental significance of fire. Various fire economies developed and biotic management began. As Native Americans accumulated horses, domestic livestock began to exert some influence on native vegetation.

With the influx of European civilization, extreme cultural stress was exerted on natural ecosystems. Many exotics were introduced. Domestic

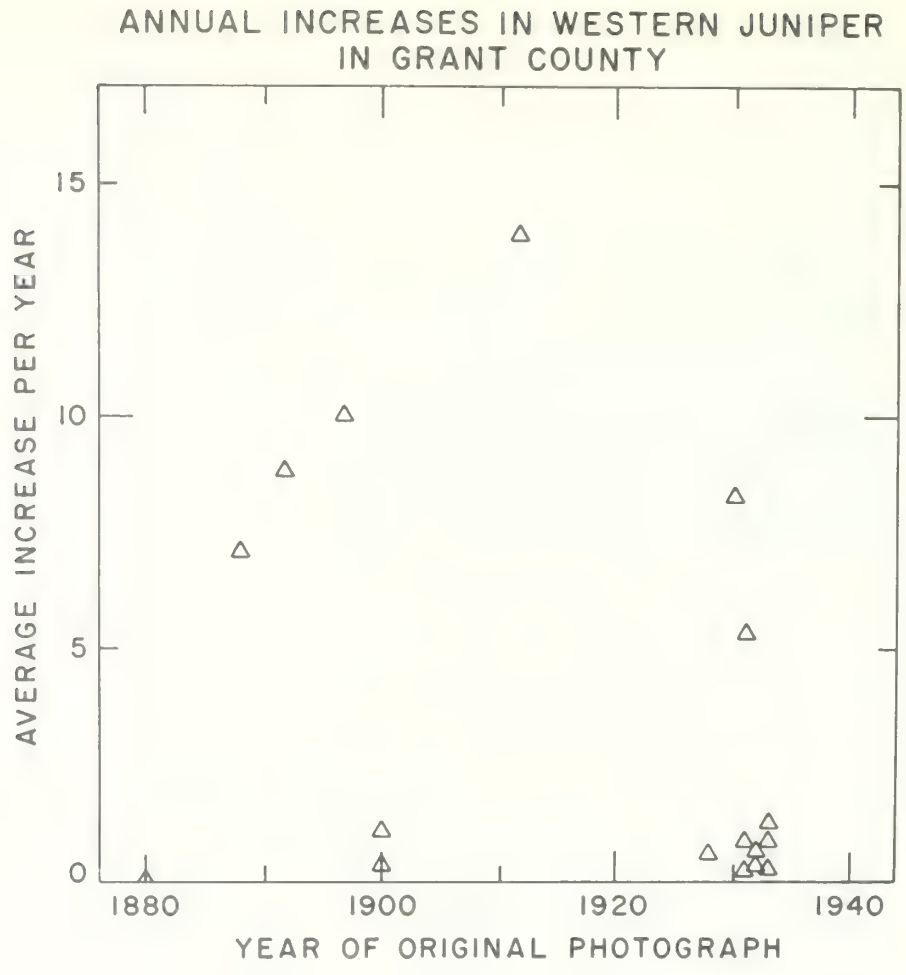

FIGURE 3. Average increases in numbers of *Juniperus occidentalis* per year in 17 photo-set comparisons.

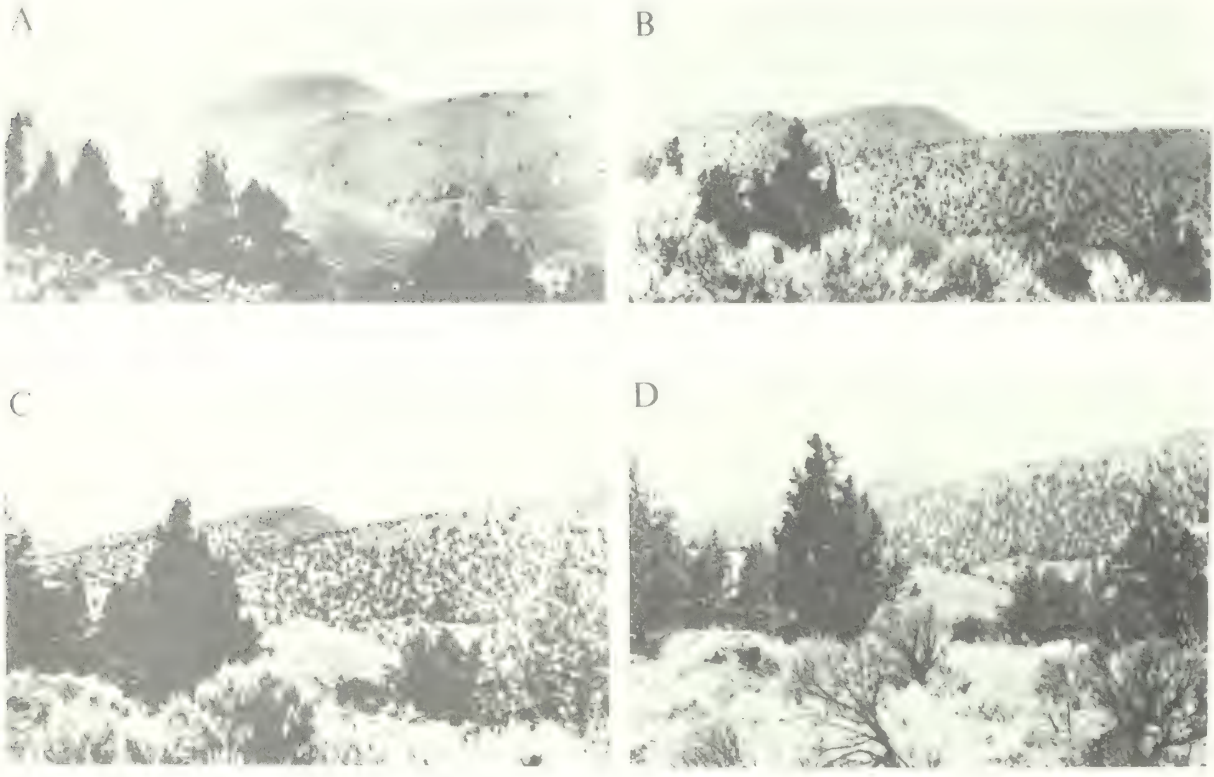

FIGURE 4. (A) 1920; (B) 1945; (C) 1956; (D) 1965.

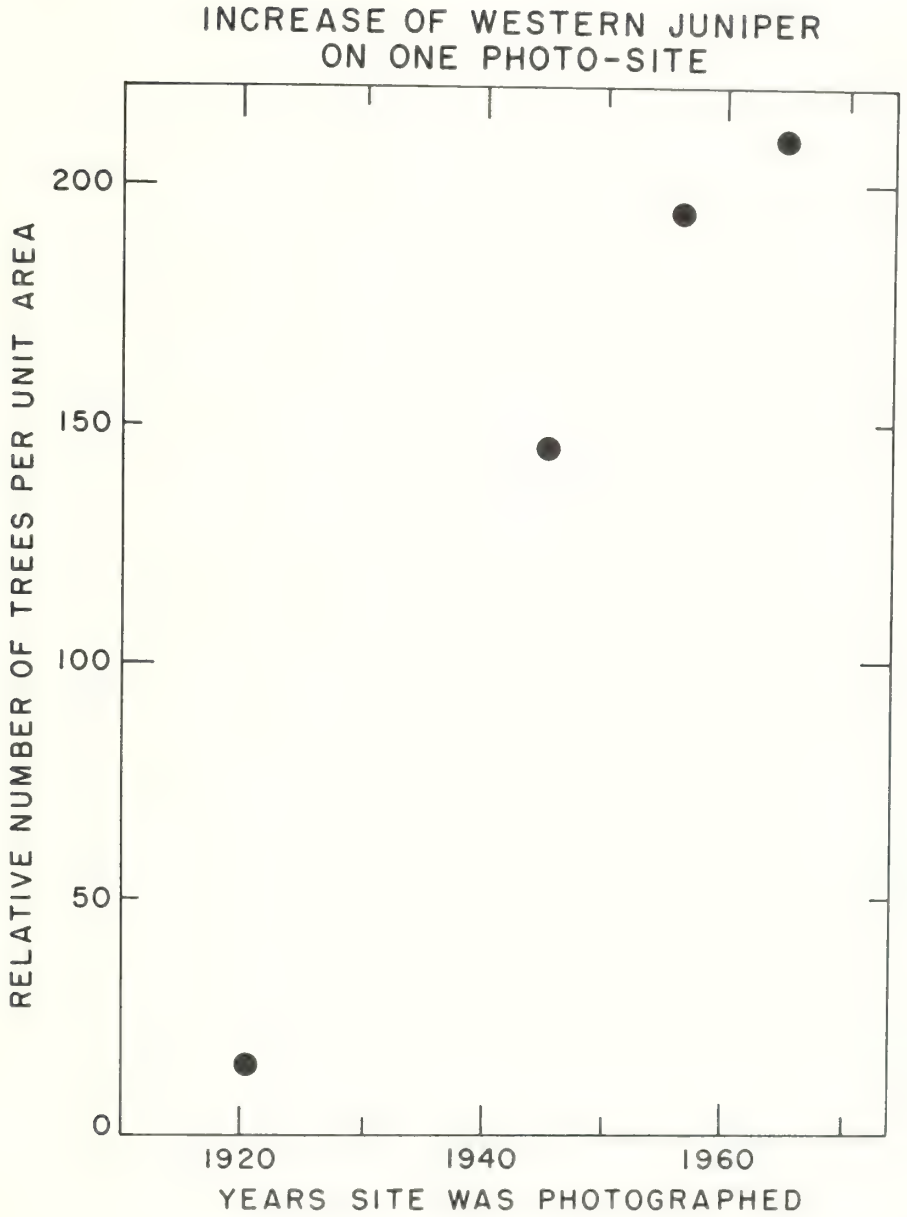

FIGURE 5. Increase in numbers of *Juniperus occidentalis* on one site from 1920 to 1965.

livestock intensified grazing pressure on the herbaceous flora. Many biotic systems were disrupted by farming. All burning was curtailed and disjunct use habits divided land according to ownership and resource distinctions.

Recently, as resource management concepts and techniques have emerged among the various Federal agencies, a trend toward reintegration of environmental forces has evolved.

Well coordinated research programs, of course, are essential in deriving an holistic knowledge of any natural system. But the methods of coordination often receive insufficient attention. Effective systems for integrating research disciplines need to be developed. A discussion of the program in which the present study is involved may help.

The direction of Park Service research derives from an overall resource or land management standard: in this case, restoration of biotic associations to their primitive condition. It is important, then, to know what environmental components are involved. In eastern Oregon these are: wildlife populations, changing vegetation, fire, livestock grazing, and man, each affecting the others. It is also important to decide which research disciplines should be applied to each of these environmental components. Ecology, history, and anthropology have each played an important part in the present program.

Data from each discipline have contributed to an understanding of the relationships between various components of change in eastern Oregon ecosystems (Figure 6). Ecological and historical data concerning wildlife populations, changing vegetation and livestock grazing were coordinated with ecological, historical and anthropological data concerning fire and man. The combination is an integrated research program which may be called "historical ecology." Using this approach an ecological history can be developed and employed in the restorative management of virtually any park environment.

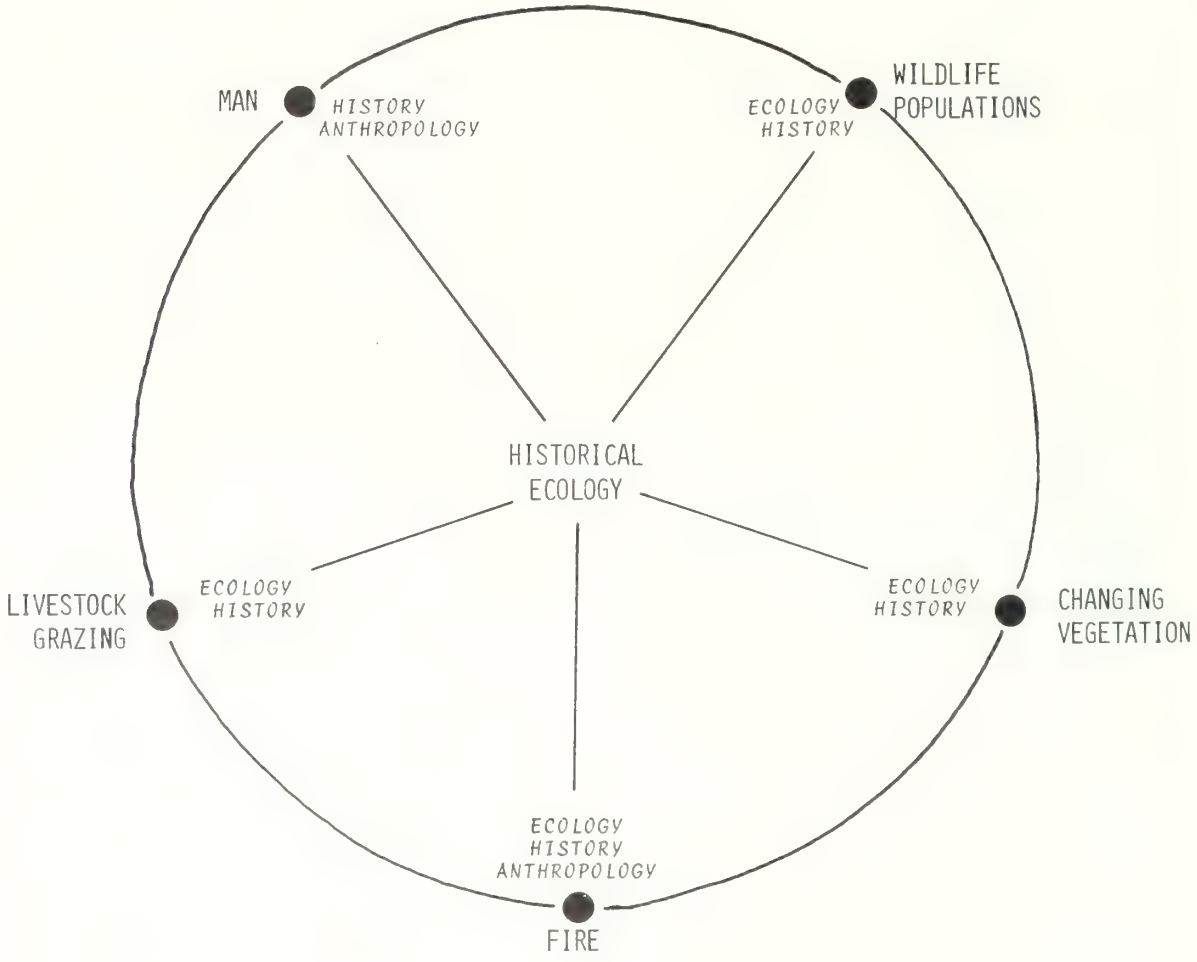

FIGURE 6. A diagrammatic method for integrating scientific land management research.

LITERATURE CITED

AGEE, J. K. 1974. Fire management in the National Parks. Western Wildlands 1(3);27-33.

BARNEY, M. A. and N. C. FRISCHKNECHT. 1974. Vegetation changes following fire in the pinyon-juniper type of west-central Utah. Journal of Range Management 27(2):91-96.

BERREMAN, J. V. 1937. Tribal distribution in Oregon. Memoirs of the American Anthropological Assoc. #47. Amer. Anthro. Assoc. Menasha, Washington.

BLACKBURN, W. H. and P. T. TUELLER. 1970. Pinyon and juniper invasion in black sagebrush communities in east-central Nevada. Ecology 51(5):841-848.

BOARDMAN, W. S. 1967. Wildfire and natural area preservation. Proceedings of the Sixth Annual Tall Timbers Fire Ecology Conference. Tall Timbers Research Station. Tallahassee, Florida. pp. 135-142.

COTTAM, W. P. and G. STEWART. 1940. Plant succession as a result of grazing and meadow dessication [*sic*] by erosion since settlement in 1862. Journal of Forestry 38:613-626.

CRESSMAN, L. S. 1956. Klamath Prehistory. Transactions of the American Philosophical Society. 46(4):377-483.

DAUBENMIRE, R. F. 1940. Plant succession due to overgrazing in the Agropyron bunchgrass prairie of southeastern Washington. Ecology 21: 55:64.

DICKEN, S. N. 1976. Oregon geography before white settlement, 1770-1840. *In:* T. Vaughan. 1976. The Western Shore. Durham & Downey. Portland.

DRISCOLL, R. S. 1964a. A relict area in the central Oregon juniper zone. Ecology 45: 345-353.

DRIVER, H. E. and W. C. MASSEY. 1957. Comparative studies of North American Indians. Transactions of the American Philosophical Society. 47(2):167-449.

FARNHAM, T. J. 1843. Travels in the Great Western Prairies, the Anahuac and Rocky Mountains, and in the Oregon Territory. *In:* R. G. Thwaites. 1904. Early Western Travels: 1748-1846. Vol. 28. The Arthur H. Clark Co. Cleveland.

FRANCHERE, G. 1854. Narrative of a voyage to the northwest coast of America in the years 1811, 1812, 1813 and 1814 or the first American settlement on the Pacific. *In:* R. G. Thwaites. 1904. Early Western Travels: 1748-1846. Vol. 6. The Arthur H. Clark Co., Cleveland.

GALBRAITH, W. A. and E. W. ANDERSON. 1971. Grazing history of the Northwest. Journal of Range Management. 24(1):6-12.

GRIFFITHS, D. 1902. Forage conditions on the northern border of the Great Basin, being a report upon investigations made during July and August, 1901, in the region between Winnemucca, Nevada, and Ontario, Oregon. U. S. Bur. Plant Ind. Bull. 15, 60 p.

HARNISS, R. O. and R. B. MURRAY. 1973. Thirty years of vegetal change following burning of sagebrush grass range. Journal of Range Management 26(5):322-325.

HUMPHREY, R. R. 1953. The desert grassland, past and present. Journal of Range Management. 6:159-164.

_____. 1963. The role of fire in the desert and desert grassland areas of Arizona. Proc. of the Second Annual Tall Timbers Fire Ecology Conference. Tall Timbers Research Station. Tallahassee, Florida pp. 45-61.

IRVING, W. 1955. Adventures of Captain Bonneville. Binfords and Mort, Publ. Portland, Oregon.

JENNINGS, J. D. 1968. Prehistory of North America. McGraw-Hill Book Co., New York, New York.

KOMAREK, E. V. SR. 1965. Fire ecology-grasslands and man. Proc. of the Fourth Annual Tall Timbers Fire Ecology Conference. Tall Timbers Research Station. Tallahassee, Florida. pp. 169-220.

KOZLOWSKI, T. T. and C. E. AHLGREN. 1974. Fire and Ecosystems. Academic Press. New York, New York.

LEOPOLD, A. S. et al. 1963. Wildlife Management in the National Parks. Report to the Secretary of the Interior of the Advisory Board on Wildlife Management.

LEWIS, M. and W. CLARK. 1959. Original journals of Lewis and Clark. ed. by R. G. Thwaites, Antiquarian Press, Ltd. New York, New York.

MINTO, J. 1900. The number and condition of the native race in Oregon when first seen by white men. Oregon Historical Quarterly. 1(3):296-315.

MOOMAW, J. C. 1957. Some effects of grazing and fire on vegetation in the Columbia Basin Region, Washington. Ph.D. Thesis. State College of Washington.

OGDEN, P. S. 1961. Ogden's Snake Country Journal: 1826-1827. ed. by K. G. Davies. The Hudson's Bay Record Society. London.

_____. 1971. Ogden's Snake Country Journal: 1827-1829. ed. by G. Williams. The Hudson's Bay Record Society. London.

RAY, V. F. 1971. Lewis and Clark and the Nez Perce Indians. Potomac Corral, The Westerners. Washington, D. C.

SAUER, C. O. 1944. A geographical sketch of early man in America. Geographical Review. 34(3):529-573.

_____. 1950. Grassland climax, fire and man. Journal of Range Management. 3:16-21.

_____. 1956. The agency of man on the earth. *In:* W. L. Thomas 1956. International Symposium on Man's Role in Changing the Face of the Earth. University of Chicago Press. Chicago.

STEWART, O. C. 1951. Burning and natural vegetation in the United States. Geographic Review. 41(2):317-320.

_____. 1956. Fire as the first great force employed by man. *In:* W. L. Thomas. 1956. International Symposium on Man's Role in Changing the Face of the Earth. University of Chicago Press. Chicago. pp. 115-133.

SWEENEY, J. R. 1968. Ecology of some "fire-type" vegetation in northern California. Proceedings of the Seventh Annual Tall Timbers Fire Ecology Conference. Tall Timbers Research Station. Tallahassee, Florida. pp. 111-125.

TOWNSEND, J. K. 1839. Narrative of a journey across the Rocky Mountains to the Columbia River and a visit to the Sandwich Islands, Chili [*sic*] & with a scientific appendix. *In:* R. G. Thwaites. 1904. Early Western Travels: 1748-1846. Vol. 21. The Arthur H. Clark Co. Cleveland.

TURNER, W. M. 1873. Scraps of Modoc History. Overland. 11(21):21-25.

UNITED STATES CENSUS. 1860-1969.

UNITED STATES CENSUS OF AGRICULTURE. 1925-1969.

WRIGHT, H. A. 1974. Range Burning. Journal of Range Management 27(1):5-11.

ALPINE AND SUBALPINE VEGETATION UNDER THE INFLUENCE OF NON-NATIVE MOUNTAIN GOATS, OLYMPIC NATIONAL PARK[1]

Ingrid C. Olmsted[2]

INTRODUCTION

The Rocky Mountain Goat (*Oreamnos americanus*) is native to the mountains of Alaska, British Columbia, Washington, Idaho and Montana. In the State of Washington, mountain goats are native to the Cascade Mountains. During the period 1925 to 1940, several deliberate as well as unintentional introductions in Alaska, Montana, Colorado, South Dakota, as well as Washington were very successful (Hanson 1950; Hibbs 1966; Hjeljord 1971; Lentfer 1966). In the late 1920's, 12-15 mountain goats were introduced to the Olympic Peninsula. The goats dispersed in an easterly and southerly fashion around to the Northeast, East and Southwest portion of the Park and just 10 years ago also to the interior. The 1976 population was estimated at 1000 (Moorhead pers. comm.). However, on one particular mountain ridge in the Northeast of the Park, the mountain goats have increased perhaps threefold during the last 15 years. The overall use pressure on Klahhane Ridge has resulted in some apparent disturbance of the vegetation.

This study will report the first results of an investigation into the current status of the vegetation and soils of Klahhane Ridge. Studies of the vegetation prior to the introduction of the mountain goats were not made. The mountain goats and their habitat have not been studied in Olympic National Park. Overuse of browse by an introduced mountain goat population into the Black Hills of South Dakota was reported (Richardson 1971).

PHYSICAL DESCRIPTION OF STUDY AREA

Klahhane Ridge. Olympic National Park is located in the extreme Northwest corner of the state of Washington. Klahhane Ridge, an East-West trending mountain, is situated in the Northeast portion of the Park.

Klahhane Ridge is bounded westwards by Mt. Angeles (1950m) and on the east by Rock Peak (1889m). The ridge top is very narrow, and the major habitat for the vegetation is on the south-facing and north-facing slopes. Most of the vegetated slopes are between 25° and 35° steep, in some rockier areas they are 35°-40°. A switchback trail used extensively by visitors leads up to the ridge on the south-facing slope and follows the ridge. A network of avalanche shutes leads from the ridge to a road.

Klahhane Ridge seems to be excellent mountain goat habitat offering rugged, steep terrain above timberline with sufficient forage. The goats are more concentrated here than anywhere else in the Park. The ridge is more confined than any other mountain. The surrounding terrain lacks the craggy rock formations of the volcanic substrate. During a recent direct count, we estimated that the whole ridge is inhabited by 180 mountain goats, with summer range of 8-9 km^2, we have about 21 mountain goats/km^2. In a stable, native population in Glacier National Park the summer range has 2.8 mountain goats/km^2 (Chadwick 1975).

Climate. The Olympic climate is decidedly maritime. Summers are usually cool and dry, winters are mild and wet. The proximity of the Pacific Ocean mediates the temperature. Precipitation varies tremendously from west to east, from 5000 mm on the coast to 1200 mm in the Northeast being strongly influenced by the topography. Precipitation falls mainly in the form of snow in the winter time. The melting snow provides most of the soil moisture for the plants in the growing season.

Geology. Two main rock types occur in Olympic National Park, sedimentary and volcanic. The core of the mountains consists of sandstone, shale and graywacke, the Northeastern and Eastern perimeter is made up of pillow basalt and volcanic breccia. The volcanic substrate is more rugged and more dissected than the sandstone. Most of the mountain goats are today distributed in the volcanic areas of the Park. Klahhane Ridge is mostly volcanic, but sedimentary rock is intermixed, sometimes making for complex combinations and very different erosion rates. The basaltic rock is harder than the shale material. This variability becomes very obvious with regard to areas that are able to produce meadows and those that are not.

HABITAT

It was necessary to map the habitat types and plant communities therein to follow the goats' activities and assess the disturbances.

I have divided the ridge into five habitat types for the summer range. The ridge falls easily into South- and North-facing aspects. The recognition of the habitat types is based on the geologic formations and vegetation. Figure 1 shows the types on the South-facing slope: I - South - facing meadows (light grey), II - Rock, (black), III - Slide-Rock (mostly stippled). The dark grey areas all along the bottom half of the Figure are densely forested.

Figure 2 is a composite of two maps of the North- facing slopes: IV - Ridge top (dark grey areas are meadows.), V - North-facing Slope.

The major extent on the South-facing slope is taken up by the meadow type. This area includes the avalance shutes. The meadows are mostly on the less stable sedimentary substrate with volcanics intermixed. There are only very small patches of meadow on the more resistant basalt. The rock type consists mostly of massive basalt or breccia and has probably the lowest plant cover of all habitats. The slide rock area is extensive and is a combination of rock outcrops and slide areas in-between, used heavily by the goats. These slides are between 30° and 35° steep and contribute a lot of erosion to the areas below even in the normal state. The erosion rate is accelerated by the goats' heavy use of these steep migration routes. One other habitat in this category is a scree slope. It has no exposed soil, a

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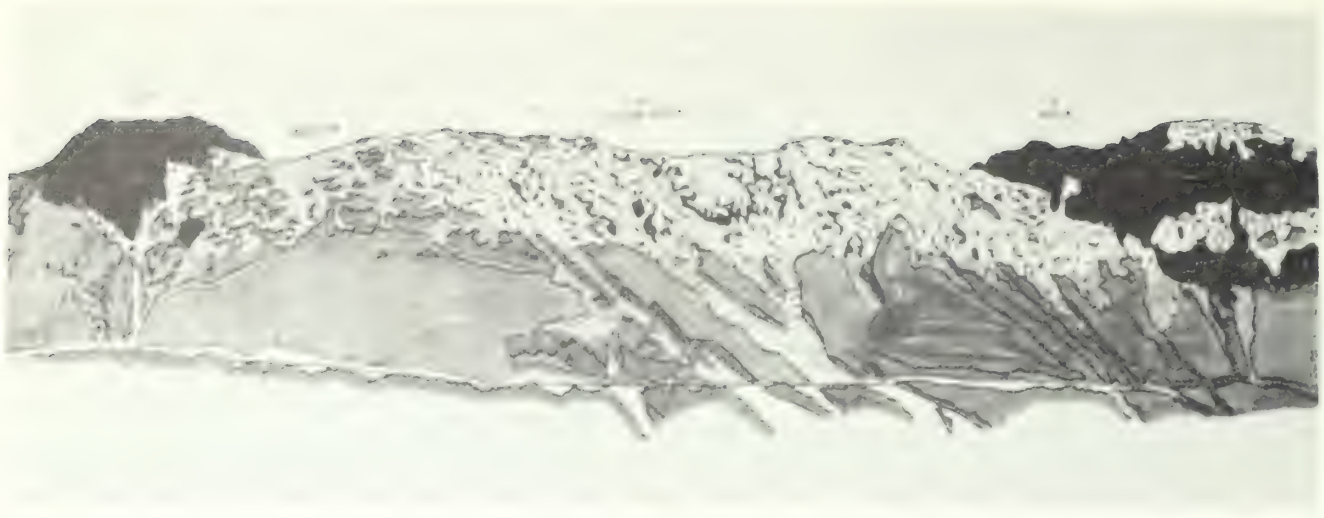

FIGURE 1. Habitat maps--south-facing slopes (explanation in text).

FIGURE 2. Habitat map--north-facing slope (explanation in text).

very sparse vegetation cover and only pioneer plants grow here.

On the ridge top, snow may stay in small amounts until September. The ridge top is very limited in extent, in places having just enough room for the trail. When it does open into some flat spots we find a meadow community.

The north-facing slopes are dominated by snow. The first shoots usually appear towards the end of July, the last snow usually melts in September, in a few places not at all. The snow depth and length of stay determine the plant communities. In many areas, there is no plant growth at all.

Table 1 gives a listing of the plant communities and their variants in each habitat type as well as the major plant species in each community. I should like to point out that these communities are similar, but not identical, to those described by Kuramoto and Bliss (1970).

On the south-facing slope, below 1600 m, are several lush tall forb communities which are not described here because the goats rarely enter these areas during the growing season. In the variants of the dry grass/forb community, the differences are mainly in the change of dominance between *Phlox diffusa, Festuca idahoensis* and *Aster paucicapitatus.* Since the slide areas in the Slide rock are narrow and long as well as steep, the plants growing here hardly form communities. *Lomatium martindalei* and *Allium crenulatum* will be the only species in certain areas, in other places either *Luina hypoleuca* or *Artemisia ludoviciana* will grow by themselves.

The Ridge top dwarf sedge meadows have the highest plant cover of all communities, often 100%. Some of these *Carex nigricans* communities are also found just below the ridge on the N-facing slopes, next to the heather community. The heath shrub community extends over the greatest elevational gradient (1450m-1800m). The scree slopes on the north-facing side are similar in substrate to the ones on the south side, but much greater in extent and with totally different plants.

MOUNTAIN GOAT BEHAVIOR AND ACTIVITIES

The goats use all communities and habitat types. Their influence is different from one place to another and the degree of disturbance depends on the activity and the stability of the habitat.

TABLE 1. Habitats and plant communities.

Habitat type	Community	Major species
I S-facing slope Meadow-type, incl. avalanche tracks	Dry grass/forbs: 3 variants between 1600-1800 M	*Phlox diffusa* *Festuca idahoensis* *Arenaria capillaris* *Aster paucicapitatus* *Aster foliaceous* *Artemisua ludovicians*
	Mesic grass/forbs 2 variants between 1700-1760 M	*Lupinus latifolius* *Achillea millefolium* *Phacelia nemoralis* *Artemisia ludovicians* *Festuca idahoensis* *Phlox diffusa*
II Rock--crevices Ledges, 1800-1950 M	Alpine cushion plants	about 30 species
II Slide rock 1600-1800 M		*Lomatium martindalei* *Allium crenulatum* *Luina hypoleuca* *Artemisia ludoviciana* *Phacelia nemoralis* *Hydrophyllum occidentalie*
IV Ridge top 1800-1850 M	Dwarf sedge Dwarf forb	*Carex nigricans* *Potentilla flabellifolia* *Antennaria lanata* *Erigeron perigrinus*
	Alpine cushion plants	about 30 species
V N-facing slope 1800-1675 M	Scree plants	*Senecio neowebsteri* *Delphinium glareosum* *Arnica cordifolia* *Epilobium alpinum*
	Lupine	*Lupinus latifolius*
1800-1450 M	Heath shrub	*Phyllodoce empetriformis* *Cassiope mertensians* *Luetkea pectinata* *Veronica cusickii*
	Dwarf sedge/forb	*Erigeron perigrinus* *Antennaria lanata* *Potentilla flabellifolia* *Carex nigricans*

Feeding. The obvious need for food brings the goats in the summer time to the subalpine zone. They follow the melting snow to take advantage of new young shoots as they appear. I have observed the goats through binoculars at very close range as they were feeding on different plants and at different stages of plant growth. They seem to prefer young shoots over everything else. Small, narrow leaves are eaten more often than any other plant part. During mid-season, when the vegetation is lush and the plants are in flower, the goats will take a mouthful out of an area, but only consume a small amount of it. The rest falls to the ground. The amount of wilted plant material that is removed by the goats may contain a lot of roots and stolons. Through observation alone I could establish which plant species the goats had eaten. There are several families that seem to be favored; they are the Compositae, the Gramineae, the Caryophyllaceae and Polemoneaceae. *Festuca idahoensis,* which is an abundant species, is taken often in all habitats where it occurs. The *Asters* are ranked in second place.

Trampling. While they are feeding or traveling to their feeding or bedding places, the goats trample on a lot of vegetation and soil as well as rock. Since most of the feeding and traveling occurs on steep slopes, loosening or removal of plants through trampling is greater than on flat terrain. The mountain goats on Klahhane Ridge travel rarely alone and most often in groups of 3-20. When 20 goats feed in the same area several days or weeks in a row, the effect on the vegetation is going to be visible.

In each habitat, one can follow distinct goat trails; most of these are almost void of vegetation, particularly on rocks where the trampling removes the plants very easily. The goats use the man-made trail often; however, the approach of visitors causes them to move away in any direction over the vegetation between switchbacks. This type of often hastened trampling accounts for a lot of plant and soil removal downslope. Since rock outcrops and massive rocks are the goat's escape cover, many trails lead to these places.

Dust-bathing. One of the common activities during the summer time is wallowing or dust-bathing. To remove insects from their bodies, mountain goats spray dirt at themselves with their feet. This activity occurs in wallows, areas which have been totally denuded. These places are numerous over the whole range and vary in size from about 1 m^2 to 120 m^2, the largest one that I have seen. The goats use many of these wallows over and over again, but they add new ones every year. When wallows are started right on top of the ridge at a very narrow point, the amount of erosion occurring is tremendous. One such wallow is three feet deep and the wind is constantly undercutting the sides and removing more soil.

The distribution of wallows on the largest south-facing meadow is shown in Figure 3. The presentation is a simplified version of the meadow and shows some of the permanent plots measured for vegetation cover.

The condition of the soil in the wallows depends on the frequency of use. Many of the dust-bathing areas look larger than they are in reality. Since most of the wallows are located on steep slopes, the spraying of soil is often directed downslope. When a goat is pawing at the lower edge of a wallow, it may move a lot of soil over and below the edge of the wallow, thereby covering vegetation below it and seemingly moving the border. At the edges of the wallows, plant roots are often exposed and wilt. The wallows may, therefore, increase without actual pawing, just by death of plants on the edge.

Bedding. The goats will often bed in the wallows. Some of the bedding places are in rocky areas or at least close to the rocks. The bedding sites that I have seen were lower in vegetation cover than the surrounding vegetation. Frequent use of the same bedding site will disturb the vegetation enough that plants will die.

Salt-licks. The goats' need for salt in early summer has been recognized by man and is used to attract the goats. In Olympic National Park, mountain goats have been trapped for marking and removal for the past three years. Trapping has been facilitated by the use of salt licks. The areas in which licks were established are visited by the goats frequently. The vegetation in these places has been destroyed for the most part because of the heavy and frequent concentration of the goats in these areas. I have observed 40 mountain goats at one time in the salt lick area.

Of the naturally occurring goat activities, the damage is ranked according to Figure 4. If we include the disturbance inflicted by the man-placed salt blocks, then the resulting destruction from the concentrated use would take first place. The trampling occurs as the most frequent activity and therefore also the most damaging in the steep Klahhane terrain. The dust-bathing removes the vegetation totally from an area, but fortunately right now this activity is not as extensive as the trampling. The ranking is very close though.

Figure 4 also shows the amount of time spent by the mountain goats in each habitat by month. If we consider the time from June through September, then the S-facing meadows are used the heaviest. Often in August and September and into October the goats come from the North-facing slope over the ridge to the South-facing slope to feed.

STATUS OF VEGETATION

Plant Cover. As a first step towards finding out the current condition of the plants I measured the vegetation cover in each habitat. In establishing plots, I made sure that there were no wallows in them, since they are devoid of vegetation. On the largest south-facing meadow (Figure 4), I chose a transect along the contour in an east-west direction, far below the trail, on which I put permanent stakes 10 m apart. Below each stake, I sampled three plots, each 1 m^2. I worked with a frame 20 cm x 50 cm. This frame fit 10 times into the 1 m^2. The individual frame was subdivided into 10 subunits of 10 cm x 10 cm. The sizes of plot, frame and subunit are shown in Figure 5. For each 10 cm x 10 cm subunit the vegetation cover was estimated.

Since there is no part of the ridge that the goats are not using, I did not find any vegetation totally untouched. For the purpose of comparison I have used the terms "least used" and "heavily used" to indicate differences within the same plant community. Table 2 lists the vegetation cover for most of the plant communities. The south-facing meadow has the largest extent of dry grass/forb community with the densest plant cover and firm topsoil. Its susceptibility to goat disturbance lies partially in the fact that the plants grow frequently in terrace formations.

The mesic grass/forb community has a much less stable soil than the dry grass/forb, possibly due to the fact that the substrate is different and the plant cover is less. In this community close to the Mt. Angeles massif, which is an escape cover for the goats, I measured a decrease in plant cover with increasing proximity to the

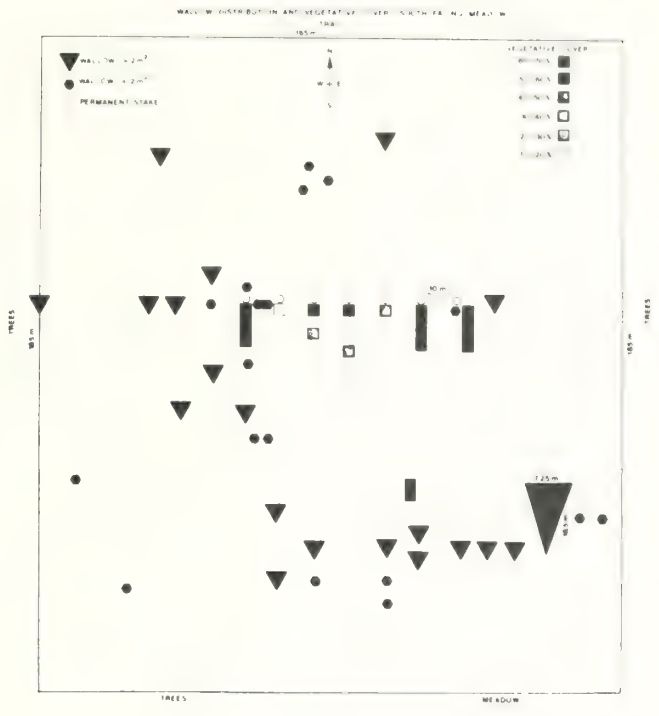

FIGURE 3.

wallow in East-west direction. Sometimes, there is a decrease in cover below a wallow in North-South direction.

However, this pattern does not always hold. On the south-facing meadow, where the wallows are abundant, the densest vegetation is sometimes found right next to a wallow.

Changes in Species Composition. A shift in certain species is occurring. I have noticed species which the mountain goats are not feeding on. Some of these species, like *Cirsium edule* and *Artemisia ludoviciana,* have become established in disturbed sites. How many other species are changing their role in a community is not known. We can only monitor from now on to see what changes occur. In the slide rock habitat, *Artemisia* has become very abundant. The habitat is constantly disturbed by the goats, but it is an unstable community in its natural state.

Since the goats eat a tremendous number of young shoots, mainly of the Compositae and Caryophyllaceae, it is conceivable that the flowering of some of these species is reduced. In some communities in which *Aster paucicapitatus* dominates I did not see any flowers. All the shoots had been picked in certain places, and flowering did not occur. *Aster foliaceous* is abundant in the dry grass/forb community, but the flowering seemed reduced as well. Two species of *Silene* are eaten heavily and in some places did not show flowers. This reduction in flowering obviously causes reduction in seeds and therefore possible reduction in plant establishment and a possible reliance on vegetative reproduction.

SOILS

In many places the soil is more disturbed than the vegetation. Apart from the actual removal of soil, its loss of structure is probably the

JUNE AND JULY:

AUGUST AND SEPTEMBER: NORTH-FACING SLOPES >

RIDGE TOP

FIGURE 4.

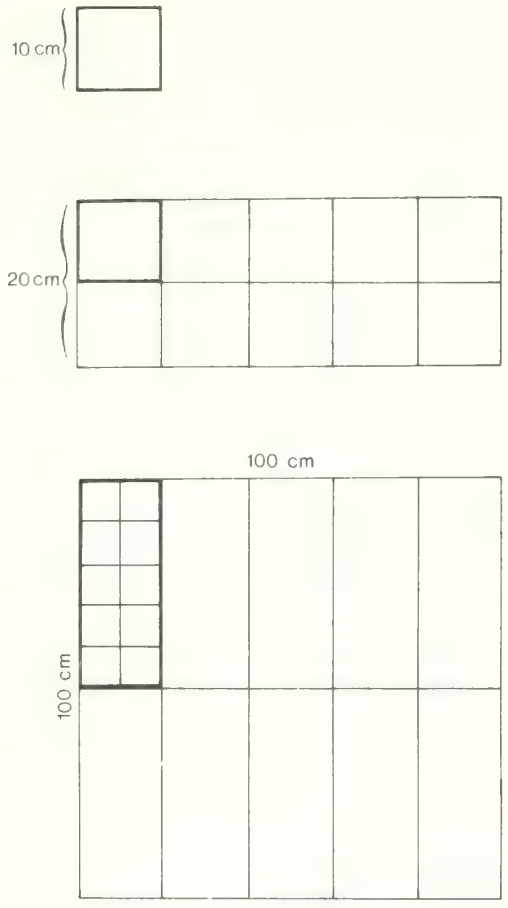

FIGURE 5. Size of sample plot and subunits.

TABLE 2. Vegetation cover.

	Habitat-community	Least used	Heavily used
I	S-facing meadow		
	Dry grass/forb	66%	10-35%
	Along switchback Trail	41%	17%
	Mesic grass/forb	54-33-24-13%	
	(decreasing cover with decreasing distance from wallow)		
II	Rock	not measured	
III	Slide-rock	35%	5-15%
IV	Ridge top		
	Dwarf sedge	95-100%	
	Dwarf forb	50-68%	
V	N-facing		
	Scree plants	26%	
	Heath shrub	90%	50%
	Dwarf forb (flat)	38%	23%
	Dwarf forb (slope)	42%	38%

TABLE 3. Bulk densities (G/CC)

Habitat	Dense	Vegetation Disturbed	None	Wallows
Meadow	.70	.87	1.09	1.08
	.52	.76	.92	1.09
	.98	.98	1.02	
		.85	.67	.93
N-facing				
Dwarf sedge-forb		.68		.83
Slide-rock		1.09	1.10	1.24

greatest disturbance. A good measure of soil disturbance is bulk density. In undisturbed vegetation, soil bulk density may be 0.50-0.80 g/cc. In disturbed soil, the bulk density may increase to one gram/cc and may even reach values as high as 2g/cc. Table 3 is a listing of bulk densities for different plant communities and wallows. The highest bulk density was measured in a wallow in the slide rock area.

CONCLUSIONS

These observations and results of the study of mountain goat/plant interrelationships will hopefully be the beginning of a long-term monitoring project which will provide information for management of the ecosystem.

The goats are changing the vegetation, and their large number on Klahhane Ridge may incur further damages and may take a long time to heal. It will be necessary to establish exclosures for monitoring succession, plant cover, revegetation of wallows and biomass. Basic data are needed before Park management can make sound decisions. The mountain goats are currently in conflict with National Park Service Management Policies which stipulate that exotic plants and animals should be removed from National Parks.

REFERENCES

CHADWICK, D. H. 1975. Monthly Progress Report Population characteristics and habitat relationships of Rocky Mountain goats in Glacier National Park, May-July, 1975.

DEBOCK, E. A. 1970. On the behavior of the Mountain Goat (*Oreamnos americanus*) in Kootenay National Park. Masters Thesis. University of Alberta.

HANSON, W. H. 1950. The Mountain Goat in South Dakota, Ph.D. dissertation, University of Michigan. 92p.

HIBBS, D. L. 1966. A literature review of Mountain goat ecology. Colorado Dept. Game, Fish and Parks and Colorado Coop. Wildl. Res. Unit Spec. Report. No. 8, 23.

HJELJORD, OLG. 1971. Feeding ecology and habitat preference of the mountain goat in Alaska. M.S. thesis, U. of Alaska 126p.

KURAMOTO, R. T. and L. C. BLISS. 1970. Ecology of subalpine Meadows in the Olympic Mountains, Washington. Ecol. Monogr. 40:317-347.

LENTFER, J. W. 1955. A two year study of the Rocky mountain goat in the Crazy Mountains, Montana. J. Wildl. Mgt. 19, 419-429.

RICHARDSON, A. 1971. The Rocky Mountain Goat in the Black Hills. Bulletin #2, South Dakota Dept. of Fish, Game and Parks.

SUCCESSION FOLLOWING GOAT REMOVAL IN HAWAII VOLCANOES NATIONAL PARK[1]

Dieter Mueller-Dombois[2]

INTRODUCTION

Goats (*Capra hircus* L.) were introduced to the island of Hawaii about 200 years ago by Captain Cook (in 1778), when they were initially kept by Hawaiian chiefs (Tomich 1969). Hawaii's natural vegetation offered particularly favorable food materials because the native plant communities evolved without the stress of mammalian herbivores. As a consequence, most endemic plants lack defense mechanisms such as thorns or impalatable chemicals. Moreover, because of the Islands' isolation, carnivorous predators were absent as well. Thus, the goats found ideal habitat conditions in the seasonally dry environments, which in the Park include three of the six major ecosystems, the montane seasonal, the submontane seasonal and the coastal lowland ecosystem (Mueller-Dombois 1976). The goats soon became feral and were reported (Marques 1905) as widespread and abundant by 1850. At that time they probably formed already dense populations in the less frequented areas of Hawaii Volcanoes National Park, particularly in the coastal lowland. Their destructive role was suspected for many years, and the Park Service took measures to reduce the goat population by organized goat drives during which from 500-5,000 goats were shot annually (Gerdes 1964).

During 1965-66 I had the opportunity to map the Park's vegetation (Mueller-Dombois 1966; Mueller-Dombois and Fosberg 1974). Upon completion of this project, I suggested to Park management the construction of a number of experimental exclosures in various locations of the Park. Several of these were built in 1968. So far two papers were published on goat exclusion effects in the Park, one on the reproduction and maintenance pattern of *Acacia koa* trees in the montane seasonal ecosystem (Spatz and Mueller-Dombois 1973) and another on the initial results of goat displacement in the coastal lowland vegetation (Mueller-Dombois and Spatz 1975).

The present paper reports on a second phase of vegetation development, which was observed from monitoring the coastal lowland exclosures from 1971 through 1976.

STUDY AREA AND METHODS

Hawaii Volcanoes National Park extends from the summit of Mauna Loa (13,680 feet = 4,170 m) in a narrow strip along its east flank downslope into the montane rain forest near Kilauea Caldera (at 3,900 feet = 1,200 m) and from here in pie-shaped form south to the Pacific coast (Fig. 1). The coastal lowland has been defined as the area from about 1,500 feet (450 m) down to sea level. It occurs as a series of gently sloping plateaus of differently aged lava flows below the major cliffs or palis (e.g., Hilina Pali, Poliokeawe Pali). Along the coast, the lowland extends in the Park over a distance of about 45 km.

Seven major vegetation types have been recognized for this area at a large map scale (Mueller-Dombois and Fosberg 1974), but on a more generalized level the eastern half can be described as a sparse scrub and the western half, the study area proper (shaded in Fig. 1), as a sparse grassland.

The mean annual rainfall in this western half of the coastal lowland is from 700-1,000 mm, with most of the rain falling in the cooler part of the year (from mid-November through mid-April). A pronounced dry season occurs during the rest of the year when the orographically dried tradewinds blow with strong desiccating power. The area is tropically warm with a mean temperature of 26°C during the dry season and 22°C during the rainy season.

The western lowland has been the traditional goat concentration center in the Park. Here, one experimental exclosure was built in 1968 at Kukalauula (site 1 on Fig. 1) and another two were built in 1971 at Puu Kaone (site 2 on Fig. 1). Site 1 is representative of much of the area of shallow (5-20 cm deep) ash pocket soil on pahoehoe that prevails in the western coastal lowland outside the more recent lava flows. Site 2 is representative of the deep (over 1 m) fine ash soils (Pahala ash) that occur in more localized areas (Puu Kaone and Puu Kapukapu). In 1965, the vegetation on the shallow ash pocket soils was mapped as open annual grassland with the pantropical grass *Eragrostis tenella* as the most conspicuous. In contrast, the vegetation on the deep ash soils was mapped as closed perennial grassland with *Chrysopogon aciculatus* and *Cynodon dactylon* as the most dominant species.

The Kukalauula exclosure at site 1 is 7-m wide and 100-m long. It was monitored since summer 1971, always during the wet and dry seasons, by measuring cover changes of the plant species with the point-intercept method (Levy and Madden 1933; Mueller-Dombois and Ellenberg 1974). Ten equally spaced, permanently marked transects were run across the exclosure, and the points were spaced 20 cm apart (i.e., 5 per meter). The inside sample consisted of 350 points and the outside sample of 250 points.

Exclosure A at Puu Kaone is also long and narrow (90 m by 10 m), and it was similarly sampled with 500 points inside and 500 points outside. The neighboring Exclosure B is a 100 m by 100 m (1 ha) fenced area. Here four 100 m^2 releves were established inside of which two were monitored regularly with each 250 points along five permanently marked 100 m long transects.

RESULTS

Kukalauula Site. Figure 2 shows the year-to-year changes in percent shoot cover of the quantitatively important species inside and outside the exclosure on the rockoutcrop habitat with shallow soil. A species was defined as quantitatively important when it occurred with a cover of at least 1% in any of the dry season (June-July) monitoring periods. This criterion left out a number of quantitatively insignificant species that will be referred to below.

[1]Contribution No. 007/4 CPSU University of Hawaii, National Park Service contract number CX 8000 6 0031.

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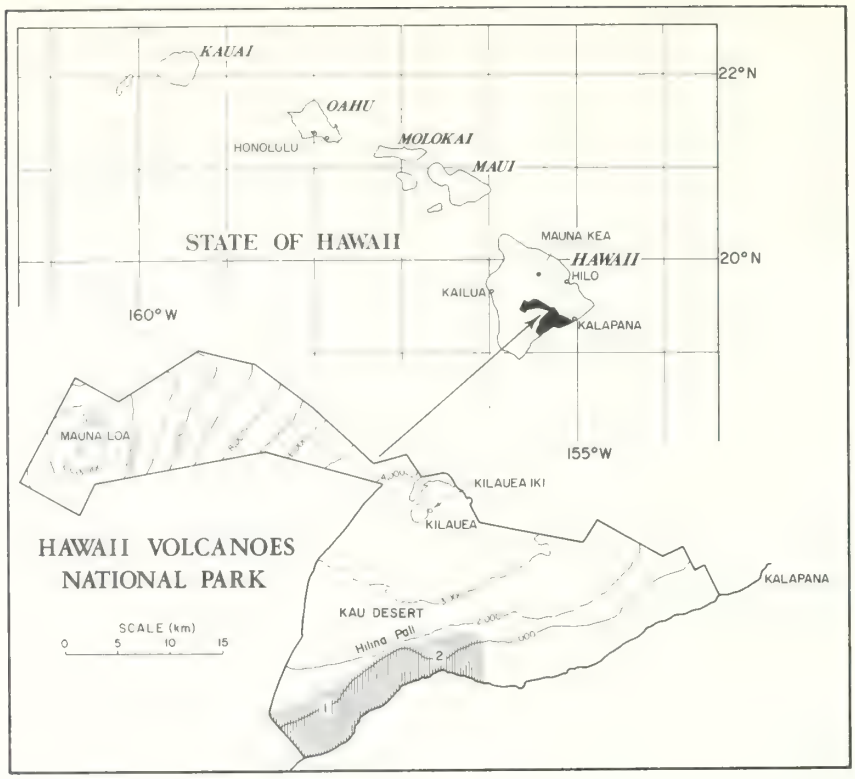

FIGURE 1. Map of Hawaiian Islands with study area in Hawaii Volcanoes National Park. 1= Kukalauula exclosure, 2 = Puu Kaone exclosure. Shaded area shows approximate extent of former *Eragrostis tenella* grassland.

Inside the exclosure occur three species with high cover (over 30% during at least one measuring period). These are two grasses, *Cynodon dactylon* (Bermuda grass) and *Rhynchelytrum repens* (Natal red top) and a herbaceous vine, *Canavalia kauensis*. The third item with high cover is dried-up shoot material, here referred to as litter. *Canavalia kauensis* is the now famous native Hawaiian vine that was described as a new endemic species by St. John (1972). In 1971 *Canavalia* was present with nearly 50% cover. In 1974 it declined to a low of 11%. Recently it has increased again to 18% in 1976. The decrease of *Canavalia* in 1973 was balanced by a great increase of litter to 46%, which was largely from dried individuals and fronds of the vine. 1973 was a particularly dry year. At that time, it appeared that *Canavalia* was drying out. However, the species recovered in 1975, although not to its original importance. Instead the bunch grass *Rhynchelytrum repens* increased steadily (except for the dry year 1973), from 1% in 1971 to 33% in 1976. *Cynodon* oscillated in quantitative importance. In 1974, it has a particularly high cover (41%) because *Canavalia* had declined so much (to 11% cover). Many of the vine fronds had shrunk and exposed the undergrowing mats of *Cynodon*. Another thick mat-forming grass, *Melinis minutiflora* (molasses grass) increased from under 1% to 9% cover in only three years, from 1973-76. *Melinis* now appears to become a serious competitor to *Canavalia*, because it grows to the same height, about 1 m, in the exclosure. Inherently low-growing plants, such as the annual grass *Eragrostis tenella*, the stoloniferous grass, *Digitaria pruriens* and the low mat-forming forb, *Desmodium triflorum*, decreased to small or insignificant cover very soon in the early stage of vegetation development. *Digitaria* is the most tenaceous of the three species and was more abundant during the moist year of 1974. Among the three shrubs (*Indigofera suffruticosa, Cassia leschenaultiana* and *Waltheria americana*), *Waltheria* had its maximum cover (5%) in 1974 at a time when *Canavalia* had retreated to a low level (11% cover). Afterwards many *Waltheria* bushes became smothered by thick mat-formers such as *Cynodon, Melinis* and *Canavalia*. *Cassia leschenaultiana* maintained a rather constant low cover of 2%, while *Indigofera*, the tallest (up to 1.5 m tall) growing shrub of the three increased to 3%. It will probably become more dominant in the future.

Outside the exclosure, the vegetation looks very different, because here the goats were still quite abundant till 1973. Only two grass species are dominant, *Eragrostis tenella* and *Cynodon*. The latter was inconspicuous in 1965 but gained ground with reduction of the grazing pressure. While it is of similar cover outside and inside, *Cynodon* grows very low appressed to the ground outside (less than 10 cm high), while inside it forms 50 cm thick mats. This grass has the greatest morphological flexibility and thus adaptability to the changing conditions in this community. Before construction of the exclosure there was no *Rhynchelytrum, Melinis, Carnavalia* or any of the three chamaephytic shrubs present. Lately these plants have become established also outside. This is very significant. It shows that the goat control program is now effectively reflected in vegetation development. Recently, *Canavalia* has become so abundant outside, that its shoot system was already measurable as 1% cover. Thus, with time, the outside vegetation at Kukalauula can be expected to develop similarly as now seen inside the exclosure.

The Kukalauula vegetation is quite rich in species. The following additional grasses occur with insignificant cover inside only: *Sporobolu*

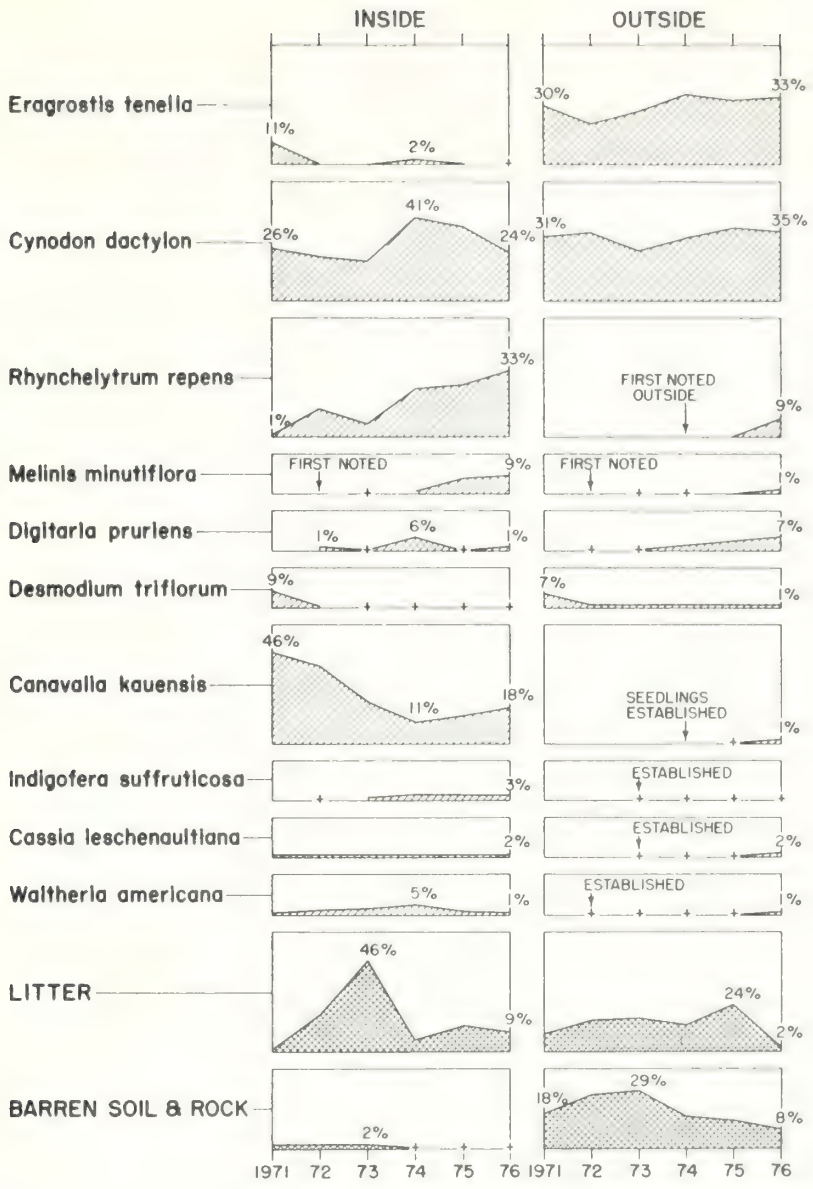

FIGURE 2. Kukalauula exclosure. Dry season measurements of cover (%) based on 350 points inside and 250 points outside. + = present with cover <0.1%.

africanus (initially with 4% cover, now only present), *Heteropogon contortus* (the Hawaiian pili grass; this was expected to increase in cover, but did not), *Andropogon glomeratus* (broomsedge), *Hyparrhenia rufa* (this African savannah grass occurred only temporarily in the exclosure, but may return).

Seven additional species occur only outside the exclosure: *Bulbostylis capillaris* (a small annual sedge), *Euphorbia hirta* (a weed establishing itself commonly on disturbed soil), *Portulaca oleracea* (a low-growing succulent), and four small slender forbs: *Gnaphalium purpureum, Linaria canadensis, Sisyrhinchium micranthum* and *Vernonia cinerea*.

Three species of insignificant cover were found both inside and outside the exclosure. These were two small perennial sedges (*Cyperus brevifolius* and *Cyperus compressus*) and one endemic low-growing succulent *Portulaca cyanosperma*.

Puu Kaone Site. Figure 3 shows the quantitatively important species on the deep ash soil inside and outside exclosure A. The differences between inside and outside became important here, since goats were practically eliminated in 1971 right after construction of the exclosure. Therefore, the outside trends are more or less a replication of the inside trends.

In 1965, this site was covered dominantly with the dense-growing, perennial, stoloniferous grasses, *Chrysopogon aciculatus* and *Cynodon dactylon*. Both are still there, but *Chrysopogon* has lost ground and occurs with less than 1% cover since 1975. Also *Cynodon* is retreating, but less so. Instead two other taller-growing grasses gained dominance rapidly after 1971, *Melinis minuti-*

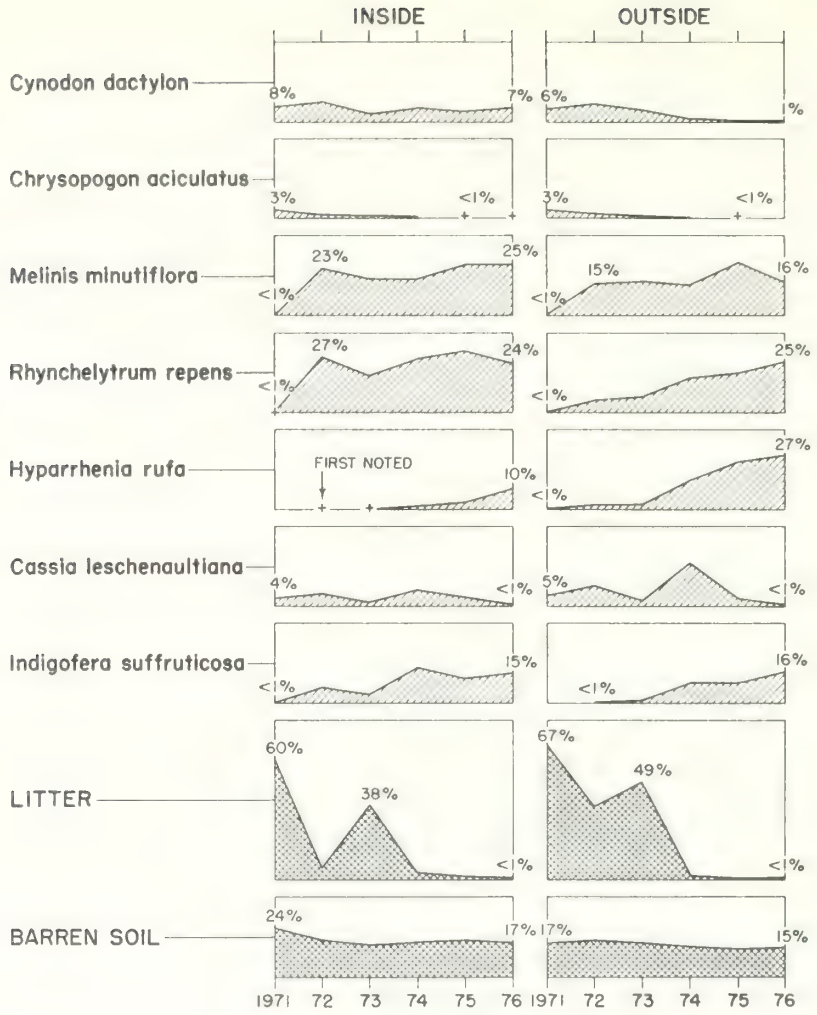

FIGURE 3. Puu Kaone exclosure A. Dry season measurements of cover (%) based on 500 points inside and 500 points outside exclosure. + = present with cover <0.1%.

flora and *Rhynchelytrum repens*. More lately (since 1973) a third grass, *Hyparrhenia rufa*, has joined the group of dominant grasses. The two chamaephytic shrubs, *Cassia leschenaultiana* and *Indigofera suffruticosa*, are also quantitatively important. *Waltheria americana* occurs only sporadically at this site. While *Cassia* oscillated in cover (for example, its cover increased in the wet year 1974, and lately declined to under 1% cover), *Indigofera* increased steadily, now being present with a cover of 15% and 16%, respectively. *Indigofera*, as the tallest growing woody plant in this locality, can be considered as indicating the successionally most advanced stage at this time (1976).

Of interest at this site is also the variation in litter. While high litter is correlated with dry years (1971 and 1973), the litter cover decreased also with the advancing succession. This can be attributed to the improvement of soil water conditions through added organic matter in the soil.

A few other species were recorded as present but with insignificant cover. These include four grasses (*Digitaria pruriens, Sporobolus africanus, Andropogon glomeratus*, and an endemic variety of *Cenchrus echinatus* var. *hillebrandianus*), two sedges (*Cyperus brevifolius, C. compressus*) eight sporadically occurring composite weeds (*Bidens pilosa, Emilia javanica, Ageratum conyzoides, Vernonia cinerea, Sonchus oleraceus, Erechtites valerianaefolia, Centaurea melitensis, Conyza* sp.), two legumes (*Desmodium triflorum, D. uncinatum*) and a few other forbs (*Oxalis corniculata, Euphorbia hirta, Solanum nigrum, Chenopodium album, Passiflora foetida* an *Psilotum nudum*).

Figure 4 shows the monitoring results of exclosure B. This one-hectare area was fenced because it was one of the lushest grassland patch at Puu Kaone. In 1965, this area was covered dominantly with *Cynodon dactylon* and lesser quan tities of *Chrysopogon aciculatus*. In 1973 the latter species was gone and *Cynodon* started to decline steadily from 50% to 16% (in 1976). Instead *Melinis minutiflora* grass mats began to overgrow *Cynodon* and now *Melinis* occurs with ove 50% cover in this exclosure. *Rhynchelytrum repe* and *Hyparrhenia rufa* (the two perennial bunch grasses) were prevented from increasing by the more aggressive competitor, *Melinis*. The shrub *Indigofera suffruticosa* increased steadily but slowly from 2% cover in 1973 to 6% in 1976. Of great importance at this locality is the invasio of the leguminous weed tree *Leucaena latisiliqua* which increased rapidly in cover from 1% in 1973 to 16% in 1976. At this site the woody plant stage is currently just beginning to be noticed. Where *Leucaena* grows, *Melinis* collapses rapidly in the shade of *Leucaena*.

DISCUSSION AND CONCLUSIONS

Herbaceous vines (except for insignificant sprigs of *Passiflora foetida*) are not included in the Puu Kaone data. However, the endemic *Canavalia kauensis* has also sprung up in two places, one of which is now being monitored. As yet, its spread on Puu Kaone is rather insignificant on an area basis. Another indigenous vine, *Ipomoea congesta*, has spread widely in recent years over the Puu Kaone grassland. Thus, one can now recognize several successional stages that occur side-by-side in the western coastal lowland.

On the shallow rockoutcrops soils, exemplified by the Kukalauula site, the most advanced stage can be described as a chamaephyte-vine stage (*Indigofera-Canavalia*) that is supported by bunch grasses, particularly *Rhynchelytrum repens*. Outside the exclosure, annuals (particularly the grass *Eragrostis tenella*) are still prevalent, but perennial mat-forming grasses (particularly *Cynodon*) and bunch grasses (particularly *Rhynchelytrum*), are now becoming dominant over large areas.

On the deep, fine ash soil, exemplified by the Puu Kaone site, the chamaephyte-vine stage (here *Indigofera-Ipomoea*) is very prevalent and is here supported mainly by the thick mat-forming grass *Melinis minutiflora*. In exclosure B, and in a few other locations on Puu Kaone the initiation of a tree stage is indicated.

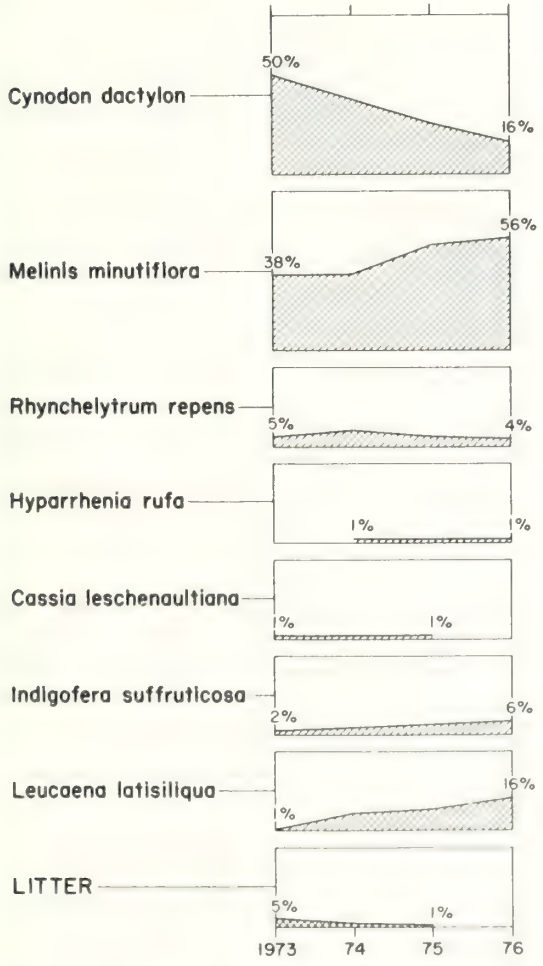

FIGURE 4. Puu Kaone exclosure B. Dry season measurements of cover (%) based on 500 points along 10 permanent transects to two relevés.

Currently two exotic weed trees are invading rapidly, one is *Leucaena latisiliqua*, the other is *Ricinus communis*. The latter occurs in a few scattered groups of 3 to 7 trees in several locations at the Puu Kaone site, and also as juvenile individuals at the Kukalauula site.

On a world-comparative basis (Walter 1971) the annual rainfall in the western lowland is high enough to support a forest, which on the deep-soil habitat can be predicted as developing into a structurally closed seasonal forest and on the rockoutcrop soil into a woodland or savannah or into a tall scrub. The woody vegetation form on the latter habitat would depend on the ecological characteristics of the major invading woody life form. For example, *Leucaena latisiliqua*, if allowed to spread, could form a closed tall-scrub.

The near-absence of native woody plant life forms in the western lowland can be attributed to the long occupation of the area by goats. Their prolonged feeding pressure resulted in exhausting the seed supply of these plants. The monitoring data indicate for the Kukalauula and the Puu Kaone exclosure A that the present successional stage in each is arrested in a chamaephyte-vine and/or chamaephyte-grass stage, respectively, because viable tree disseminules have not yet arrived there as shown by the absence of seedlings. Moreover, it seems rather unlikely that native trees will become established naturally within a reasonable time for two main reasons, the lack of seed sources of trees adapted to cope with grass and chamaephyte competition and the current spread of exotic weed-trees.

This poses new challenges to Park management for its ecosystem restoration program. The first step was the removal of goats through systematic fencing. This action was very successful as shown by the vegetation monitoring data. If the Park is to be managed for remaining as natural as possible, the next step should be a control program for the two exotic tree species (*Leucaena* and *Ricinus*) that threaten to become the next dominants in succession. Individuals of both tree species have been chopped down periodically, but the thoroughness of the control has to be increased. As shown by the data (on Fig. 4) the *Leucaena* cover in Puu Kaone exclosure B increased from 1% to 16% during the last three years in spite of several eradication attempts. Apparently, these were not yet frequent enough.

As a third step it would seem appropriate to establish, on an experimental basis, a few seed source centers by planting native dry-zone tree species, such as *Canthium odoratum, Diospyros ferrea, Erythrina sandwicensis* and others that can still be found within a three-mile limit of the formerly goat-infested territory. However, care should be taken that the area does not become an arboretum. Seed trees should be planted in strategically located places and in aggregation rather than as scattered individuals. Careful records should be kept by marking the seed source centers on large-scale maps and by monitoring them on a continuous basis.

An alternative third step may be tried for selected parts within the western lowland. This would be to arrest the plant succession in the bunch grass stage by controlled burning. There is some evidence (*fide* Vogl 1969) that the Hawaiians used fire in the dry lowlands to maintain pili grass (*Heteropogon contortus*), which they may have brought along to be cultivated and used as roof thatching material (Fosberg 1972).

Pili grass is still present in the area. It came up in the Kukalauula exclosure, but never assumed a dominant role there.

Further research is necessary on both of the step 3 alternatives suggested. The objective should not be to reestablish either native trees or pili grass in the western coastal lowland on a broadcast basis no matter what the cost in manpower, but to provide for a modification or shift in succession that permits the return and continued existence of native biota in as natural a framework as possible.

LITERATURE CITED

FOSBERG, F. R. 1972. Guide to Excursion III, Tenth Pacific Science Congress, Revised Edition. Published by University of Hawaii, Honolulu. 249 p.

GERDES, R. J. 1964. History of the Feral Goat Control Program of Hawaii Volcanoes National Park. Mimeo. Report, Hawaii Volcanoes National Park Headquarters. 17 p.

LEVY, E. E. and E. A. MADDEN. 1933. The Point Method of Pasture Analysis. New Zealand J. Agric. 46: 267-279.

MARQUES, A. 1905. Goats in Hawaii. Thrum's Haw. Annual for 1906, pp. 48-55. Honolulu.

MUELLER-DOMBOIS, D. 1966. The Vegetation Map and Vegetation Profiles p. 391-441 *in* Atlas for Bioecology Studies in Hawaii Volcanoes National Park by M. S. Doty and D. Mueller-Dombois. Hawaii Botan. Science Paper No. 2. 507 p. Republished as Hawaii Agric. Exp. Sta. Bull. 89 (1970).

MUELLER-DOMBOIS, D. 1976. The Major Vegetation Types and Ecological Zones in Hawaii Volcanoe National Park and Their Application to Park Management and Research. In Press, Proceedings, First Conference in Nat. Sci., Hawaii Volc. Nat. Park.

MUELLER-DOMBOIS, D. and H. ELLENBERG. 1974. Aims and Methods of Vegetation Ecology. Wiley and Sons, Inc., New York. 547 p.

MUELLER-DOMBOIS, D. and F. R. FOSBERG. 1974. Vegetation map of Hawaii Volcanoes National Park (at 1:52,000). CPSU-Hawaii Tech. Report No. 4. 44 p.

MUELLER-DOMBOIS, D. and G. SPATZ. 1975. The Influence of Feral Goats on the Lowland Vegetation in Hawaii Volcanoes National Park. Phytocoenologia 3(1): 1-29.

ST. JOHN, H. 1972. *Canavalia kauensis* (Leguminosae) a new species from the Island of Hawaii. Hawaiian Plant Studies 39. Pacific Science 26(4): 409-414.

SPATZ, G. and D. MUELLER-DOMBOIS. 1973. The Influence of Feral Goats on Koa Tree Reproduction in Hawaii Volcanoes National Park. Ecology 54(4): 870-876.

TOMICH, P. Q. 1969. Mammals in Hawaii. B. P. Bishop Mus. Spec. Publ. 57. Bishop Museum Press, Honolulu, Hawaii. 238 p.

VOGL, R. J. 1969. The Role of Fire in the Evolution of the Hawaiian Flora and Vegetatio Reprinted from Proceedings, Ann. Tall Timbers Fire Ecol. Conference, pp. 5-60.

WALTER, H. 1971. Ecology of Tropical and Subtropical Vegetation. Oliver & Boyd, Edinburgh. 539 p.

THE USE OF UNIFORM ECOSYSTEM PARAMETERS TO CHARACTERIZE NATURAL AREAS[1]

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INTRODUCTION

For more than a quarter of a century, ecologists and other biological scientists have been grappling with the problem of identifying quantifiable characteristics of ecosystems (McIntosh 1974). Parameters such as population numbers, biomass, diversity, equitability and various types of productivity measures characteristic of various ecosystems have been proposed and argued (Hairston 1959). While many specific ecosystems have been characterized parametrically, there is still no coherent rule for relating one ecosystem to another or for relating plant and animal parts of an ecosystem to each other. Pressures from society are requiring that ecology quickly become a science that is useful both in the definition of important natural areas and in outlining management procedures for these areas (Clark 1974). Of necessity, ecology will have no period of several hundred years to develop the powerful analytical tools and paradigms necessary to deal coherently with environmental interactions. Tools and methods must be developed quickly that can compare and evaluate nonsimilar ecosystems even if that evaluation cannot yet be performed optimally.

The Natural Landmarks Program has been developed by the National Park Service as one method of defining our remaining nationally significant natural areas. Ecologically such areas should represent the major characteristics of a physiographic province or biome, a stable biotic climax community, habitats supporting threatened or endangered species, relict floral or faunal associations and areas showing significant evidence of major ecological processes such as successional change (National Park Service 1971). Applicability of these criteria to a candidate area is judged, albeit qualitatively, by the investigator. The final determination of which areas possess national significance must be based on comparison of the candidates. Such comparison is extremely difficult, since each system will usually exhibit a different sub-set of the desired characteristics. Definition and use of quantifiable parameters from each system could therefore aid greatly in comparison of candidate areas.

Comparison of candidate areas should ideally show the investigator both the usefulness of the candidate as a natural area and help define the natural integrity of the area. The comparison must be based on indices that can be easily measured in all of the system types under consideration. In coastal plain areas, it is necessary to compare terrestrial forests and fields with wetland areas. The plant communities can be easily compared by measuring numbers and density of species, biomass, annual productivity, successional age and species diversity. For animals, information is more difficult to obtain rapidly and reliance must be placed on secondary information sources. The only data available are generally population numbers and sometimes densities.

The purpose of this paper is to suggest some ways in which unlike ecosystems can be compared and ways in which the plant and animal subsystems may be related. This latter problem involves the concept of habitat usage. Natural areas investigated under the National Landmarks Program are used here to illustrate ecosystem comparison. The areas are classified under the National Park Service Theme Studies for the Atlantic Coastal Plain (Smithsonian Institution 1974) and the Eastern Deciduous Forest (Waggoner 1975). The three areas emphasized here were selected from a total of nine areas investigated based on data availability and representativeness of ecosystems. They are Blackwater National Wildlife Refuge (NWR), Eastern Neck NWR and Zekiah Swamp.

MATERIALS AND METHODS

Estimation of plant productivity and biomass in coastal plain communities is difficult to assess in a uniform manner due to marked differences in growth habit. Forested areas were sampled by measurements of tree height, DBH and radial increment growth. In each forest area several 10 x 10 meter plots were established. Tree height was assessed with a Haga altimeter. Average radial increment was determined by boring to the tree center as determined by DBH measurements and dividing number of growth rings by the tree radius. Both overstory and understory vegetation was measured in this manner. Shrubs were noted as to height and diameter and occasionally harvested for weight estimates. Undergrowth was harvested in several 1 m^2 quadrats within each larger quadrat. Fresh and dry weights were determined for all harvested material.

Field and marsh areas were measured by harvest techniques. At least four quadrats were clip-harvested in each marsh or field area with quadrat size from 0.1-1.0 m^2 depending on heterogeneity of the vegetation. Only measurements of aboveground standing crop were attempted. Fresh and dry weights were determined as above.

Incremental annual production in forest trees was computed from the radial growth increment determined by core measurements coupled to height increment curves for the major species. The formula:

$$V_i = \frac{\pi}{2} (r_2^2 - r_i^2)h$$

was used to determine incremental annual volume increase where r_2 is the radius at the end of the growing season, r_1 the radius after the previous growing season, and h the tree height. Tree height increase was determined from studies of forest productivity (Ovington 1957; Whittaker and Woodwell 1969). Dry wood density was derived from standard tables (Weast 1974). Corresponding leaf biomass was then estimated from bole-branch-leaf ratios (Whittaker 1961; Ovington 1957).

[1]My thanks to the National Park Service Natural Landmarks Program for making possible the collection of data used in this paper. I also wish to thank refuge personnel of Blackwater NWR and Eastern Neck NWR for supplying important information and documentation of these areas.

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Annual net primary productivity was calculated by multiplying incremental volume increase by dry wood density and correcting for leaf production. Total production or standing crop was computed in forest areas by setting $r_1 = 0$ and reapplying the formula. Stand age was computed directly from core measurements. Species diversity was based on numbers of individual plants per square meter and was computed using Shannon's Index:

$$\bar{H} = -\sum_i \left(\frac{n_i}{N}\right) \log\left(\frac{n_i}{N}\right)$$

where n_i are the individuals in each species and N represents the total number of individuals.

For animal populations detailed measurements of species productivity must be estimated or extrapolated from sketchy data on populations, range and biomass. Even population numbers are usually only available on game mammals, major predatory birds, major shore birds, waterfowl or endangered species. For this study data of sufficient accuracy and species coverage were obtainable only on two national wildlife refuges. Population numbers were taken from interviews with refuge personnel and from refuge publications. Information on areal coverage of various ecosystems was obtained from the same sources. Data on individual biomass were taken from standard sources (Giles 1971; Cruickshank 1973).

Annual net primary productivity was not extrapolated for animals since this process is particularly difficult without knowledge of the population age distribution. Total biomass or standing crop was calculated based on numbers and individual mean biomass. Biomass was divided by the habitat area used by each species to give standing crop per unit area. Species biomass was also weighted in terms of energy flow in an attempt to clearly define utilization of habitat. The systems were divided into producers, herbivores and carnivores. Producers were assigned unit energy value, herbivores were assigned a value of 10 and carnivores a value of 100 based on Slobodkin's early work on trophic energy relations (Slobodkin 1960). Weighted animal biomass was then divided by plant productivity to define a relative utilization parameter (U_r).

RESULTS AND DISCUSSION

Table 1 illustrates comparative values of net primary productivity (NPP), biomass (aboveground standing crop), stand age and species diversity ($\bar{H}$) for five representative ecosystem types in Maryland. The range of productivity values compares closely to other studies (Whittaker and Woodwell 1969; Reichle 1975) except that NPP for the mixed hardwood forest is higher than usually reported. Productivities are dependent on the age and composition of the communities, past history, substrate and factors of environmental stress. As such, productivity values are comparable from one area to another only within a given ecosystem type. Thus, if two brackish marshes are compared to determine which has a higher NPP or higher diversity, some conclusions may be drawn from the comparison. Comparison of marshes to forest or even brackish to fresh marsh, however, is not very enlightening in terms of productivity biomass, diversity or successional age. Instead some common denominator must be drawn from one or more of these parameters that links the various systems and also includes the animal communities.

Table 2 and 3 contain data on numbers of individuals and available habitat for wildlife species within the Blackwater and Eastern Neck Wildlife Refuges. The species lists are not complete but include only those faunal groups for which good estimates or actual counts were available. It should be noted that the same were used for both areas. Habitat area used was derived from knowledge of the total areas of forest, field marsh and open water habitat coupled to assumptions that each species only used certain ecosystems. Ducks were assumed to utilize marsh and open water primarily while geese used fields and marsh. Habitat used by other animals was determined by their known dietary preferences, nesting and feeding behavior.

Biomass and weighted biomass totals are shown in Table 4 where they are compared with plant productivity. The habitat utilization coefficient (U_r) is defined as the weighted biomass (B_w) divided by the NPP. This coefficient measures (roughly) the ratio of the energy utilization by major faunal groups to the total available energy supply. Since other species were not included due to lack of population information, the habitat utilization coefficient does not reflect the actual utilization of available resources but only a relative rating of utilization of the species shown.

The lower value of U_r for Blackwater NWR indicates that significant productivity is going to species not listed, decomposers, export or organic accumulation. Eastern Neck NWR has lower NPP but a better utilization by upper trophic levels. Th

TABLE 1. Comparative parameter value of five ecosystems types in three Maryland natural areas.

Community	Dominant	Net primary productivity g/m^2 · yr	Biomass (standing crop) g/m^2	Diversity $\bar{H}$	Stand age yr
Mixed hardwood forest	*Liquidambar* sp. *Liriodendron* sp.	1270	32,400	0.436	61
Mixed swamp forest	*Quercus* sp. *Pinus* sp.	790	27,100	0.759	71
Field (uncultivated)	*Digitaria* sp. *Gnaphalium* sp.	204	204	0.276	--
Brackish marsh	*Spartina patens* *Scirpus olneyii*	380	380	o.297	--
Fresh marsh	*Spartina cynosuroides* *Habenaria* sp.	610	204	0.215	--

TABLE 2. Faunal data and calculations from Eastern Neck NWR.

Wildlife type	Mean biomass per organism kg	Number of organisms	Weighting factor	Habitat area ha	Calculated biomass kg	Calculated biomass per hectare kg	Weighted biomass per hectare
Deer *Dama virginicus*	63	450	10	1490	28,350	19.0	190
Delmarva fox squirrel *Sciurus niger cinereus*	1	250	10	1490	250	0.2	2
Bald eagle *Helianthus leucocephalis*	5	4	100	300	20	0.03	3
Peregrin falcon *Falco peregrinus*	1	0	100	--	--	0.0	0
Osprey *Pandion haliaetus*	4	10	100	800	40	0.05	5
Heron *Ardea* spp.	5	40	100	800	200	0.3	30
Canada goose *Branta canadensis*	5	10,000	10	1590	50,000	31.4	314
Ducks (Anatinae)	1	6,500	10	800	6,500	8.1	81
Swans (Cygninae)	11	6,000	10	800	66,000	82.5	825

TABLE 3. Faunal data and calculations from Blackwater NWR.

Wildlife type	Mean biomass per organism kg	Number of organisms	Weighting factor	Habitat area ha	Calculated biomass kg	Calculated biomass per hectare kg	Weighted biomass per hectare
Deer *Dama virginicus*	63	400	10	1130	25,200	22.3	223
Delmarva fox squirrel *Sciurus niger cinereus*	1	250	10	1130	250	0.2	2
Bald eagle *Helianthus leucocephalis*	5	22	100	3640	110	0.03	3
Peregrin falcon *Falco peregrinus*	1	2	100	4770	2	0.0	0.04
Osprey *Pandion haliaetus*	4	8	100	3640	32	0.01	1
Heron *Ardea* spp.	5	20	100	3640	100	0.02	2
Canada goose *Branta canadensis*	5	80,000	10	4370	400,000	91.5	915
Ducks (Anatinae)	1	40,000	10	3640	40,000	11.0	110
Swans (Cygninae)	11	0	10	3640	--	--	0

results are consistent with observable conditions at the two areas. Eastern Neck is not heavily managed for specific waterfowl or endangered species' use although populations of these animals are high. Blackwater, on the other hand, is intensively managed for Delmarva fox squirrel and Canada geese. This management has resulted in high productivity from cleared pine forest and cultivated fields, but has apparently not been overly beneficial to wildlife in general. In addition, fluctuating water levels and controlled burning of the marsh has resulted in decay and loss of prime marsh area to large exposed mudflats. The habitat utilization coefficient therefore seems to be indicative, in this case, of the integrity and overall health of the ecosystem. This process needs to be performed on a much larger sample of natural areas, however, before it can be accepted as a representative indicator. Unfortunately, the data required to perform the

TABLE 4. Comparison of floral productivity and faunal biomass at two national wildlife refuges.

Natural area	Net primary productivity NPP g/m^2	Faunal biomass g/m^2	Weighted faunal biomass (B_w)	Habitat utilization coefficient ($U_r = B_w/NPP$)
Eastern Neck NWR	591.3	14.10	145.0	.245
Blackwater NWR	702.5	12.50	125.6	.178

calculations are not available in most natural areas without a concerted study of both plant and animal communities.

Some ecologists have recommended the classification of natural areas in economic terms (Odum and Odum 1972). This is an important eventual goal in the protection of natural areas against encroachment. Early planning and control of development and resource management are also important factors (Gaskin and Stottlemyer 1974). Other methods can be employed, however. Private landowners can often be successfully encouraged to hold their property in a wilderness condition. State natural resource agencies and private conservation organizations can similarly be encouraged to obtain easements or sale of nationally significant areas. To this end it is not necessary to define economic value but only natural values which can and should be identified on biological grounds.

Characterization of natural areas in a quantitative (though approximate) manner would provide overall advantage to the environmental sciences and ecological research in terms of a baseline data set on a wide variety of areas. Currently, each ecological province in the United States is characterized by a few, extremely well-documented sites owned by universities or research institutes. Documentation of some of the many natural areas studied in the Natural Landmarks Program would greatly enhance baseline data availability.

CONCLUSIONS

Ultimately, natural area evaluation must include both plant communities and their animal inhabitants. These must be dealt with on a comprehensive and uniform basis. Certainly, the problem may be too difficult for complete quantification. The value of the last representatives of an endangered species is nearly infinite since replacement is impossible. A forest may or may not be considered more valuable than a marsh. Such comparison of values will require judgmental decisions which should be based, to the extent possible, on quantifiable and uniform ecological factors.

Parameters such as biomass, productivity, diversity and successional age are all useful for comparing a given ecosystem type to the norm for that system. More important, however, are parameters which indicate overall health and integrity of the food web and the ecosystem. One such parameter, proposed here, is the habitat utilization coefficient U_r. While calculations of U_r require approximations and deletions of certain community components due to lack of data, the coefficient can prove useful if productivity of major species are well-known in two or more areas. Refinements of the habitat utilization concept are both desirable and necessary. Such refinements might include calculations of available forage and closer definition of range and cover requirements. Even the limited calculation shown above, however, seems to be useful in certain cases and should be extended to other natural areas in order to check its validity.

LITERATURE CITED

CLARK, J. 1974. Coastal Ecosystems & Ecological Considerations for Management of the Coastal Zone. Conservation Foundation, Washington, D.C.

CRUICKSHANK, A. D. 1973. A Guide to Eastern Central North American Birds. Simon and Schuster, New York.

GASKIN, P. and J. R. Stottlemyer. 1974. Ecological and economic principles in park planning: the Assateague National Seashore Model. Coastal Zone Management Journal, 1 (4) : 395-413.

GILES, R. H. (ed.). 1971. Wildlife Management Techniques. Third edition. The Wildlife Society, Washington, D.C.

HAIRSTON, N. G. 1959. Species abundance and community organization. Ecology, 40 : 404-41(.

McINTOSH, R. P. 1974. Plant ecology 1947-1972. Ann. Missouri Bot. Gard., 61 : 132-165.

NATIONAL PARK SERVICE. 1971. The Natural Landmarks Program. U.S. Dept. of the Interior, Washington, D.C. GPO # 1971-483-417/16.

ODUM, E. P. and H. T. ODUM. Natural areas as necessary components of man's total environment. Trans. 37th N. Amer. Wildlife Natural Resources Conf., Washington, D.C.

OVINGTON, J. D. 1957. Dry-matter production by *Pinus sylvestris* L. Ann. Bot., N.S., 21 : 287-314.

REICHLE, D. E. 1975. Advances in ecosystem analysis. Bioscience, 25(4): 257-264.

SLOBODKIN, L. B. 1960. Ecological energy relationships at the population level. Amer. Nat., 94 : 213-236.

SMITHSONIAN INSTITUTION. 1974. Survey of Natural Areas of the Atlantic Coastal Plain: Ecological Themes, Vol. 3. Prepared by Cente for Natural Areas, Office of International an Environmental Programs for National Park Service, U.S. Dept. of Interior, Washington, D.C.

WAGGONER, G. S. 1975. Eastern Deciduous Forest Vol. 1, Southeastern Evergreen and Oak-Pine Region. National Park Service, U.S. Dept. of the Interior. Washington, D.C.

WEAST, R. C. (ed.). 1974. Handbook of Chemistr and Physics (55th edition). CRC Press, Cleveland, Ohio.

WHITTAKER, R. H. 1961. Estimation of net primary production of forest and shrub communities. Ecology, 42(1) : 177-180.

WHITTAKER, R. H. and G. M. WOODWELL. 1971. Measurement of net primary production of forests. Unesco, Proc. Brussels Symp. 1969. Ecology and Conservation, 4 : 159-169.

THE NATURAL LANDMARKS PROGRAM

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The first and foremost tasks in resources management are the identification of the various resources and a determination of the importance or significance of each within a certain geographic area. From a biological standpoint, the inventory of biota and the delineation of ecosystem types or plant community types in a map format are obvious first steps in resource management. Yet it is my observation, that in terms of centralized information, we really know very little about the overall biological resources of our Nation. At the present time, there is not even a generally well-accepted classification of vegetation types for the United States. The U.S. Office of Endangered Species is now moving forward with respect to the identification of threatened and endangered species other than vertebrates, but this has been a long time in coming. University and college scientists and other naturalists have for hundreds of years studied aspects of the ecology of particular species and, especially more recently, have studied species more in relation to their total environment; yet often such worthwhile information has been buried in obscure scientific journals and probably more commonly in personal notes which never see the light of day and, after the inevitable death of the investigator, are virtually lost to mankind.

The alteration of our natural environment and its associated threats to our national biological and geological resources is occurring at a rate approaching the speed of light. Nationwide, we are losing valuable resources without, in many cases, ever knowing that we are losing them. Rational, intelligent resources management decisions, or land use decisions if you will, cannot be made due to the lack of a coordinated resource inventory or data base. The only places where such decisions have been made are in certain areas either owned by the public or various private conservation oriented groups or individuals. As will happen, a certain percentage of these decisions have been colossal mistakes such as the mule deer fiasco on the Kaibab Plateau.

The point being made is that we need quickly to begin to coordinate data on national resources, developing an inventory of such and then determining which resource areas are of prime significance for the preservation of ecological diversity, structure and function. Protection of viable gene pools as well as basic unmodified ecosystem function is certainly an aspect of resource management that is of paramount importance. Strict ecosystem preserves as well as a system of manipulative experimental reserves need to be established in order to protect our natural heritage through the long term. The National Environmental Policy Act of 1969 (NEPA) sets forth in Section 101(b) that

> . . . it is the continuing responsibility of the Federal Government to use all practicable means, consistent with other essential considerations of national policy, to improve and coordinate Federal plans, functions, programs and resources to the end that the Nation may . . . preserve important historic, cultural and natural aspects of our national heritage, and maintain, wherever possible, an environment which supports diversity and variety of individual choice.

This act calls for the decisions to be made as to what is important for the preservation of our total natural heritage.

One small program within the National Park Service is attempting, on a nationwide basis, to help get a handle on the two "first tasks" of resources management, noted above, as well as the "natural area importance decision" called for in NEPA.

The Natural Landmarks Program, which was administratively created by the Secretary of the Interior in 1962, is managed by the National Park Service pursuant to authority contained in the Historic Sites Act of 1935. The objectives of the Natural Landmarks Program are: (1) to encourage the preservation of sites illustrating the geological and ecological character of the United States, (2) to enhance the educational and scientific value of sites thus preserved, (3) to strengthen cultural appreciation of natural history, and (4) to foster a greater concern in the conservation of the Nation's natural heritage. Under this program the Service strives to assure the preservation of such a variety of nationally significant natural areas that, when considered together, they will illustrate the diversity of the country's natural environment.

In contrast to the actual units in the National Park System, natural landmarks are nationally significant natural areas which are in varying ownership, e.g., private, State, Federal. The National Landmarks Program is a voluntary, recognition program and neither ownership nor responsibility for the area changes with designation. Instead, following designation of a landmark by the Secretary of the Interior, the owner(s) is notified that his property has been determined to be of national significance as a superlative example of our natural heritage and he is invited to voluntarily register the property. This registration act is a gentleman's agreement made between the owner(s) of the landmark and the Secretary of the Interior stipulating that the owner(s) intends to preserve the site in such a way as to maintain its inherent natural integrity. This registration act is not legally binding and, therefore, long-term preservation of a registered natural landmark is not as certain as in a unit of the National Park System.

Natural landmarks are determined as a result of a fairly thorough selection process. The National Park Service is presently conducting studies, typically through contract with expert university scientists, of various natural regions of the United States. These natural regions are based largely on the physiographic provinces described by Fenneman (1928), although certain

[1]Natural Landmarks and Theme Studies Unit, National Park Service, Denver Service Center, Denver, Colorado.

modifications have been made (NPS 1969). Map I delineates these natural regions. Natural region studies describe and classify the important ecosystem types or community types occurring within a particular region and then provide an inventory of natural areas which significantly illustrate each ecosystem type previously described. Sites are assigned a priority by the natural region study team based on a comparative analysis of similar sites. Important factors considered in this comparative study include the naturalness or integrity of the site, the ecological diversity of the site, the rarity or threat to the ecosystem type, the presence of endangered or threatened biota, the relictual or distributional significance of the site and other similar factors. In addition, each natural region study contains similar information on important geological areas. However, this paper will emphasize the ecological portion of the Natural Landmarks Program.

A second phase of study involves the on-site evaluation of sites highly recommended in the natural region study. This on-site evaluation is also conducted via contract to competent scientists, usually located within the same state as the area to be evaluated. Emphasis in contracting both the natural region studies and the on-site evaluations of ecological sites is usually given to botanists, especially plant ecologists, though this is certainly not universally the case. The on-site evaluation provides more detailed information on each site, a recommended boundary, and a significance statement which briefly states why the site is, or is not, considered to be of national significance. In most instances, the on-site evaluation studies are conducted by a different scientist thus providing a "second opinion" as to the relative ecological significance of the site.

Once both of these steps are completed, the National Landmarks Program staff reviews and verifies the information available, makes additional contacts with other scientists and finally makes a determination as to whether or not the area appears to qualify as a natural landmark. The primary test is one of national significance. National significance is ascribed to those superlative areas which are true, accurate and essentially unspoiled examples of our national heritage. The Natural Landmarks Program staff presents the best areas to the Secretary of the Interior's Advisory Board on National Parks, Historic Sites, Buildings and Monuments which meets biannually in Washington, D.C. The Advisory Board then makes recommendations to the Secretary with whom rests the ultimate authority for the establishment of natural landmarks.

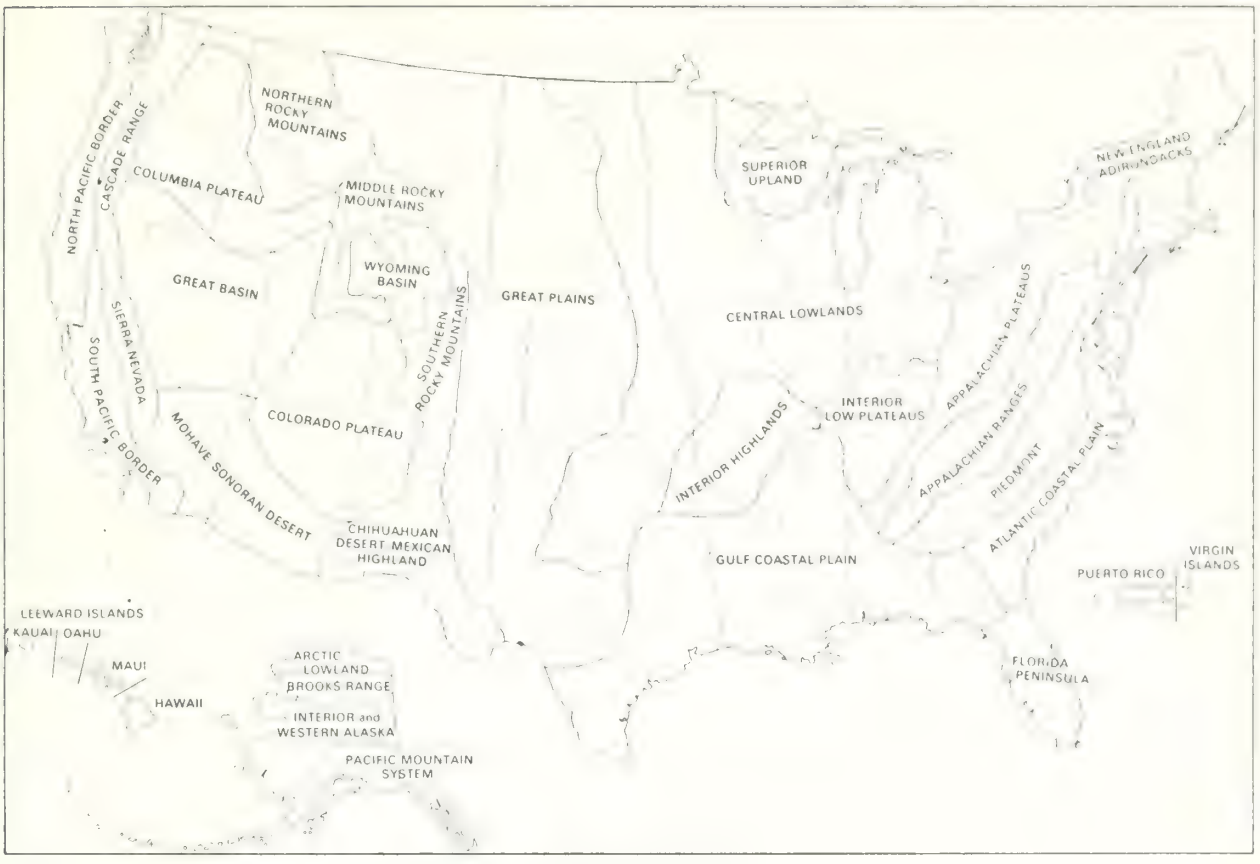
The National Registry of Natural Lnadmarks is the official listing of all natural landmarks and is published periodically in the *Federal Register*. At present, there are 433 established natural landmarks.

Designation as a natural landmark provides protection primarily as a result of the National Environmental Policy Act of 1969. This Act provides that for all federally financed or licensed activities which have a significant effect on the environment, an environmental impact statement must be written considering, among other things, the occurrence of important natural areas in the selection of alternatives and mitigating actions. Several states across the Nation have comparable laws regarding state-funded or licensed projects. The principal protection provided by natural landmark designation, therefore, is to call attention to areas containing exceptional natural values so that intelligent planning and land use decisions can be facilitated and if significant natural resources are potentially affected, mitigating actions can be taken to minimize the environmental impact. Numerous situations have occurred where proposed plans have been significantly altered and even abandoned due, at least in part, to the presence of natural landmarks at proposed project sites.

Formal agreements between the National Park Service and the U.S. Forest Service, U.S. Fish and Wildlife Service, and the Bureau of Land Management concerning the designation of natural landmarks on these public lands have created a more permanent form of preservation for these sites. Information on registered natural landmarks is provided to each administering agency so that the information can be incorporated into the management plans for the appropriate public land units. Such plans form the basis for the type of management permitted. Natural landmark designation requires that the integrity of the natural area be maintained; however, the specific type of use permitted is left up to the particular bureau administering the property. In other words, various types of use may be permitted as long as the significant natural values of the site are not impaired. Such compatible uses might include nondestructive scientific use, interpretation for the public, fishing, nature study, photography, hiking and other basically nonconsumptive uses.

Registered natural landmarks have also been established on other federal lands including those administered by the U.S. Air Force, U.S. Navy, U.S. Marines, U.S. Army, the Energy Research and Development Administration, Bureau of Reclamation, Bureau of Indian Affairs, and the U.S. Coast Guard. In most instances, the landmark designation brought the special significance of these particular sites to the attention of decision makers. The registration of these sites by the respective owners has helped to insure the preservation of several significant natural areas. Registration of natural landmarks on state-owned lands has also helped to insure the long-term protection of significant areas. In some instances, registered natural landmark status merely provides another "layer of protection" to an already recognized natural area but it does reflect perhaps the highest level of importance, that of national significance. In many instances, however, designation as a natural landmark provides the initial, official recognition of important natural areas. This is especially true with sites in private ownership.

While no absolute legal protection is afforded registered natural landmarks, the recognition factor has proven to be quite effective as a means of preservation. The National Park Service is continuously providing information concerning the locations of significant natural areas, regardless of ownership, to those public and even some private organizations responsible for planning developments. This information is received in a very appreciative manner and is relied on heavily in the planning phases of development, thus avoiding the needless destruction of known important natural resources. At the present time, the Natural Landmarks Program staff knows of only two instances where natural landmarks have been impacted to the point of losing their inherent natural integrity. Further, Land and Water Conservation Fund monies have been used in several instances by states to acquire natural landmarks for State Natural Areas or other preservation land use categories. The Nature Conservancy, a private, nonprofit, natural area preservation organization, also has information on existing natural landmarks as well as potential natural landmarks (sites under study) to assist



MAP 1. Natural regions.

them in setting priorities for their natural area acquisition efforts. The record shows that the Natural Landmarks Program has been effective in its efforts to encourage the preservation of nationally significant natural areas through the process of recognition on both public and private lands.

The establishment of natural landmarks depends heavily upon the information provided by scientists. The locations of endangered and threatened flora and fauna, the occurrences of disjunct and relict plant communities, the site of outstanding representative examples of regionally typical ecosystem types, and other similar information are all essential to the efficient functioning of the Natural Landmarks Program in its efforts to recognize nationally significant natural areas. Such information can only best be provided by scientists. The Natural Landmarks Program staff is fully aware of the sensitivity of certain types of information including the precise locations of endangered and threatened species, the locations of significant fossil deposits, the occurrences of outstanding, noncommercial caves, and the like. Such information is treated with great care. Advice on the possible limited dispersal of this information is obtained from scientists knowledgeable of the area as well as the potential threats to the site's continuing integrity. It is vitally important that information on outstanding natural areas be made available so that man's development does not unknowingly destroy unique areas needlessly. The efforts of the National Park Service in this regard are helping to avoid land use plans being made in ignorance of significant ecological information.

Through the natural region studies and subsequent on-site evaluations, much data, previously buried or otherwise generally unknown, is coming to the surface in a synthesized fashion and an inventory of our most precious and vital natural areas across the country, in public and in private ownership, is being developed. The Natural Landmarks Program is attempting to make at least a first cut at those tremendously important ecological and geological areas which can be termed nationally significant and thus critically important for the preservation of our natural heritage. Resource managers and other decision makers now have another important tool to indicate what is considered important to save when the tough resourse-use decisions have to be made and these decisions are getting tougher and tougher as greater and greater demands are being made of our environment.

LITERATURE CITED

FENNEMAN, N. M. 1928. Physiographic Divisions of the United States: Association of American Geographers, Annals 18; p. 261-353.

NATIONAL PARK SERVICE. 1972. Part Two of the National Park System Plan: Natural History. Government Printing Office, Washington, D.C. 140 p.

NATURAL AREA CLASSIFICATION SYSTEM: A STANDARDIZATION SCHEME, II

Albert E. Radford[1] and J. Dan Pittillo[2]

INTRODUCTION

Preservation of our Natural Heritage requires a holistic study of our biotic and abiotic environment. Plant and animal communities are the result of species interaction, reaction and coaction with climate, soil, geology, hydrology, topography and hydrography within a province through time. All of these elements or themes have to be included in any comprehensive classification of the natural features and processes. This natural area classification system is an effort to make (a) the study of floristic (faunistic) and vegetational systematics and (b) the classification of elements of the ecosystem for ecological characterization, classification, nomenclature and identification of plant (and animal) species and communities more efficient and effective. (See Radford et al. 1976).

The System is based upon the following assumptions:

1. Each species is selectively and uniquely adapted to a habitat.

2. Species diversity is related to habitat diversity within an area.

3. Habitat diversity is related to the diversity of species, climate, geology, soils, hydrology, topography within an area.

4. Species assemblages are recurring combinations under similar habitat conditions within an area at a given time.

5. Species assemblages are the result of the interaction of species and habitat diversity in an area through time.

The natural themes for any province are: (a) Vegetation (with animal dependents), (b) Climate, (c) Soils, (d) Geology/Hydrology and (e) Topography/Hydrography--all the interacting but independent systems that compose the Ecosystem. The basic energy driving the system is sunlight; the basic raw materials are from the intrusive and extrusive magmas, oceans, and atmosphere. Vegetational (with animal dependents) composition, distribution, and development are dependent upon climate, soils, geology, and topography acting through time. Climate (microclimates) is dependent upon vegetation, soils, geology and topography. Soil composition, distribution and development is dependent upon vegetation, climate, geology, and topography acting through time. Geological structures, formations, and sedimentary rocks are dependent upon climate, vegetation, soils, topography and time. Topographic land forms and features, structures and development are dependent upon climate, vegetation, geology, soils and time. All of these independent but interacting and interdependent themes and systems form the bases for the natural area classification schemes used in this report.

The ecological natural history themes for any province study or any conservation effort should provide the framework for a comprehensive survey of biotic and abiotic features. All types of communities from the pioneer to the climax developed during time over the different rock and water types under each significant climatic regime on the major topographic-hydrographic features should be included in the representative site samples of a complete survey of the area. The successional communities, the topo-edaphic climaxes and the continua should be part of the master theme study or conservation effort. Biogenesis has to be integrated with pedogenesis in explaining the present and past development of species and communities; climatogenesis and phylogenesis have to be coupled with succession and soil formation to explain the present composition and distribution of biotic assemblages. In order to understand the origin, migration and evolution of species, floras and faunas as well as the productivity and composition of present communities, man will have to try to conserve the total diversity of species in as broad a range of habitats as possible within the different climates in each province.

SYSTEM

This Natural Area Classification System, based primarily on Vascular Plants, has been designed for inventory and analysis of Natural Areas, Vegetation, Floras, and Rare and Endangered Species in the eastern United States. This system has been devised to cover (1) all types of successional communities; (2) all types of topo-edaphic climaxes; (3) all vanishing, rare, endangered or relict species, communities and ecosystems; and (4) all disjunct species and communities. The application of a broad natural area classification for any province is necessary for perspective in theme analysis and categorization and for a complete conservation of our Natural Heritage.

Hierarchically the classification system (Table 1) has three orders or levels: the first, *System*, with a suborder (1a) in some of the themes, e.g., "subsystem" for vegetation and "suborder" for soils; the second, *Class*, with a suborder (2a) in some of the files, e.g., "community class" for vegetation and "subgroup" for soils; and the third, *Type*, with a suborder (3a) in some of the columns, e.g., "community type" for vegetation and "series" for soils. The themes or vertical files are Vegetation, Climate, Soils, Geology/Hydrology, Topography/Hydrography and Physiography. In the Geology/Hydrology and Topography/Hydrography themes the geologic and topographic characters would usually be used for upland and flatland systems; and hydrologic and hydrographic characters for the wetland and aquatic systems.

VEGETATION

The vegetation community system, first order, is based primarily on plant habit arranged in a time or successional theme from pioneer annuals to climax angiosperm forests (I-XV)' with upland or flatland (I-VII) and lowland (VIII-XV) topose-

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TABLE 1. Natural area classification system summary

GENERAL ORGANIZATION									
LEVEL	SYMBOL	VEGETATION	CLIMATE	SOIL	GEOLOGY/HYDROLOGY		TOPOGRAPHY/HYDROGRAPHY		PHYSIOGRAPHY
1	S	Community System	Climatic Regime	Soil Order	Rock Formation	Water System	Land-form	Water Body	Physiographic Region
1a	SS	Community Subsystem	Climatic Regime	Soil Suborder	Rock Class	Water Subsystem	Land-form	Water Body	Physiographic Region
2	CCC	Community Cover Class	Temperature Zone	Soil Great Group	Rock Class	Water Class	Topo. Feat.	Hydro. Feat.	Physiographic Province
2a	CC	Community Class	Temperature Zone	Soil Subgroup	Rock Class	Water Class	Topo Feat.	Hydro. Feat.	Physiographic Province
3	CCT	Community Cover Type	Moisture Class	Soil Family	Rock Type	Water Type	Relief	Relief	Physiographic Subprovince
3a	CT	Community Type	Moisture Class	Soil Series	Rock Type	Water Type	Relief	Relief	Physiographic Subprovince

VEGETATION

1. SYSTEM(S)	1a. SUBSYSTEMS (SS)
I. PIONEER HERB	A. Basic, B. Calcareous, C. Carbonaceous, D. Ferruginous, E. Saline, F. Siliceous Pioneers
II. PERENNIAL FORB	A. Basic, B. Calcareous, C. Carbonaceous, D. Ferruginous, E. Saline, F. Siliceous Forbs
III. GRASS	A. Basic, B. Calcareous, C. Carbonaceous, D. Ferruginous, E. Saline, F. Siliceous Grasses
IV. SCRUB-SHRUB	A. Basic, B. Calcareous, C. Carbonaceous, D. Ferruginous, E. Saline, F. Siliceous Shrubs
V. WOODLAND	A. Basic, B. Calcareous, C. Carbonaceous, D. Ferruginous, E. Saline, F. Siliceous Woodland
VI. GYMNOSPERM FOREST	A. Basic, B. Calcareous, C. Carbonaceous, D. Ferruginous, E. Saline, F. Siliceous Gymnosperms
VII. ANGIOSPERM FOREST	A. Basic, B. Calcareous, C. Carbonaceous, D. Ferruginous, E. Saline, F. Siliceous Angiosperms
VIII. VASCULAR AQUATIC PLANT	A. Fresh, B. Brackish, C. Salt, D. Bog, E. Calcareous, F. Alkaline Aquatic Herbs
IX. WETLAND PIONEERS	A. Fresh, B. Brackish, C. Salt, D. Bog, E. Calcareous, F. Alkaline Wetland Pioneers
X. MARSH HERBS	A. Fresh, B. Brackish, C. Salt, D. Bog, E. Calcareous, F. Alkaline Marsh Perennials
XI. MARSH GRASS	A. Fresh, B. Brackish, C. Salt, D. Bog, E. Calcareous, F. Alkaline Marsh Grasses
XII. WET SCRUB-SHRUB	A. Fresh, B. Wet Brackish, C. Wet Salt, D. Bog, E. Wet Calcareous, F. Alkaline Shrubs
XIII. LOW WOODLAND	A. Fresh, B. Wet Brackish, C. Wet Salt, D. Bog, E. Wet Calcareous, F. Alkaline Woodland
XIV. LOWLAND GYMNOSPERM FOREST	A. Fresh, B. Wet Brackish, C. Wet Salt, D. Bog, E. Wet Calcareous, F. Alkaline Gymnosperms
XV. LOWLAND ANGIOSPERM FOREST	A. Fresh, B. Wet Brackish, C. Wet Salt, D. Bog, E. Wet Calcareous, F. Alkaline Angiosperms

sequences related to moisture (see the Natural Area Classification Summary). 'Algal, bryological and animal systems will be added to the classification scheme. The first suborder is a combination of Community Subsystem and Rock/Water Class; e.g., Basic Pioneers, Calcareous Perennials, Wet Calcareous Shrub. The second order is composed of Community Cover Classes (Table 2) which are combinations of distinctive physiognomic assemblages with habitat-habit characters; e.g., Spring succulents, Grass balds, Pine barrens. The Community Cover Classes are broad groups or assemblages of plants that have been described in the literature over a long period of time. As more inventory experience is gained, the list of Cover Classes will be extended. The second suborder consists of Community Classes which are characterized by dominants in a broad or generic sense in each layer of the community; e.g., Fagalean--Ericalean Community Class might be a combination of oaks (or a single one) in the canopy with a shrub layer below dominated by one or more heaths. The third order of vegetation is the Community Cover Type which would have only the stand dominant indicated; e.g., Eastern Hemlock, Sea Oats, Purple Laurel (Table 3).

The basic *Community Type*, third suborder, should be based on quantitative data for a biotic assemblage with a uniform microclimate and edaphic situation (pH, moisture and texture classes should be relatively uniform throughout the area). A one-layered community type would be denoted by a monomial; e.g., *Phragmites communis* (Reed grass community). Stratified (two-layered) communities are indicated by a binomial with the first name based on dominant canopy species and the second on the dominant "subcanopy species, e.g.,

Community type: *Chestnut oak--Low blueberry*
Canopy dominant Subcanopy dominant
(Shrub layer with more cover than herb layer, herbs scattered or essentially absent)
Community class: *Oak-hickory forest--Heath*

Community type: *Buckeye-basswood--Glade fern*
Canopy codominants "Subcanopy" dominant
(Herb layer with more cover than shrub, shrub layer essentially absent)
Community class: *Southern Appalachian Hardwoods--Filicalean perennials*

Community type: *Scirpus americanus--Sagittaria subulata*
Emergent dominant Submerged dominant
Community class: *Cyperaceous perennials--Alismatalean perennials*

Those communities with three distinctive strata would have a trinomial as the community type name: e.g.,

Community type: Chestnut oak--Mountain laurel--Galax
Canopy dominant Shrub dominant Herb dominant
(Cover value (5) for each)
Community class: *Oak-hickory forest--Heath--Diapensialean perennials*

Community type: Water tupelo--Duckweed--Coontail
Canopy dominant Floating dominant Submerged dominant
Community class: *Cornalean forest--Lemnaceous herb--Nymphaealean herb*

TABLE 2. Vegetation.

(Classification based primarily on habitat and habit)
Community Systems I-XV (I-VII non-aquatic, VIII-XV aquatic); Community Subsystems A-F; Community Cover Classes 1-70; Community Classes 1-112 and Community Cover Types in separate sections at the end of Vegetation.

I. Pioneer Herb System
- A. Basic Pioneers
- B. Calcareous Pioneers
- C. Carbonaceous Pioneers
- D. Ferruginous Pioneers
- E. Saline Pioneers
- F. Siliceous Pioneers
  1. Fall annuals
  2. Spring annuals
  3. Spring succulents
  4. Summer annuals
  5. Summer succulents

II. Perennial Herb System
- A. Basic Perennials
- B. Calcareous Perennials
- C. Carbonaceous Perennials
- D. Ferruginous Perennials
- E. Saline Perennials
- F. Siliceous Perennials
  1. Bulbous perennials
  2. Cespitose perennials
  3. Cushion mat perennials
  4. Fern perennials
  5. Rhizomatous perennials
  6. Succulent perennials

III. Grass System
- A. Basic Grasses
- B. Calcareous Grasses
- C. Carbonaceous Grasses
- D. Ferruginous Grasses
- E. Saline Grasses
- F. Siliceous Grasses
  1. Sedge-rush flat
  2. Shortgrass prairie
  3. Tallgrass prairie
  4. Mixed grass prairie
  5. Grass bald
  6. Grass barren
  7. Grass dune
  8. Grass flat
  9. Grass ridge
  10. Grass savannah
  11. Grass slope
  12. Grass zone
  13. Grass field
  14. Grass waste
  15. Sedge tundra

IV. Scrub-Shrub System
- A. Basic Shrubs
- B. Calcareous Shrubs
- C. Carbonaceous Shrubs
- D. Ferruginous Shrubs
- E. Saline Shrubs
- F. Siliceous Shrubs
  1. Heath bald
  2. Shrub bald
  3. Heath barren
  4. Shrub barren
  5. Heath cliff

TABLE 3. Community cover types (selected).

CONIFERS OR GYMNOSPERMS

c1. Chamaecyparis thyoides (L.) B.S.P. Atlantic white cedar
c7. Abies balsamea (L.) Mill. Balsam fir SAF-5
c16. P. elliottii Engelm. Slash pine SAF-84

QUERCINE SPECIES

q1. Quercus alba L. White oak SAF-53
q17. O. macrocarpa Michx. Bur oak SAF-42
q46. Blackjack oak-Black oak
q79. Willow oak-Overcup oak

HARDWOODS

h7. A. saccharum Marsh. Sugar maple
h27. B. papyrifera Marsh. Paper birch

SHRUBS

s3. Hypericum fasciculatum Lam.
s9. Zenobia pulverulenta (Bartram) Pollard Zenobia

GRAMINOIDS

g23. Rhynchospora corniculata (Lam.) Gray Horned rush
g41. Ammophila breviligulata Fernald American Beachgrass

VASCULAR AQUATICS

a3. Najas guadalupensis (Sprengel) Magnus Bushy pondweed
a4. Nelumbo lutea (Willd.) Persoon Yellow nelumbo
a7. Nymphaea odorata Aiton Water-lily

PIONEER ANNUALS

p6. Arenaria uniflora (Walter) Muhl. Rockwort
p8. Salicornia bigelovii Torr. Dwarf saltwort
p10. Diamorpha smallii Britton

If the community has four distinctive strata then the community type name would be indicated by the dominant from each of the four layers. If vines occur in two or more layers and have a total cover value of (5), then vine dominant(s) should be part of the community type name following (/) at the end of the binomial; e.g., *Chestnut* Oak--Low blueberry/Catbrier. Epiphytes with a large cover value should be indicated by (//), then dominant ephiphyte name; e.g., *Water tupelo-Duckweed--Coontail//Spanish moss.*

(Within a "uniform" topo-edaphic and microclimatic situation the habitat is not uniform. The Buckeye-basswood--Glade fern community used as an example above has a few stumps and fallen logs with a distinctive flora (hummophytes), a few seepages with some species restricted to them (crenophytes) and walking fern-covered boulders (petrodophytes). In an inventory of this (or any) community the species should be listed by sub-habitat; e.g., hummophyte, crenophyte, petrodophyte, epiphyte or calciphytes on a calcareous lens or shell sand in a siliceous-based community, dry mesophytes over shallow soil in an otherwise mesic habitat, pyrophytes around an old campsite fireplace, aletophytes on trails through the community, etc., within the general community or habitat summary for that particular area or site.

CLIMATE

The first order of the climatic file should include the climatic regimes according to Köppen or some other climatologists, e.g., I. *Tropical Climate (A),* II. *Arid Climate (B),* III. *Mesothermal Climate (C),* IV. *Microthermal Climate (D),* V. *Cryothermic (polar) Climate (E).* The second order might pertain to temperature, such as the classification of C. Hart Merriam; e.g., I. *Arctic Zone,* II. *Hudsonian Zone,* III. *Canadian Zone,* IV. *Transition Zone,* V. *Upper Austral Zone,* VI. *Lower Austral Zone,* VII. *Tropical Zone,* and the third order should include the edaphic moisture classes as that of the U.S. Department of Agriculture, e.g., 1. *Very Dry-Xeric,* 2. *Dry-Xeric,* 3. *Dry-Mesic,* 4. *Mesic,* 5. *Wet-Mesic,* 6. *Wet-Hydric,* 7. *Hydric.*

SOILS

The soil file should be based on the *Soil Taxonomy* (1975) of the U.S. Department of Agriculture with soil order as first order; e.g., Alfisols, Aridisols, Entisols, Histosols, etc., and soil suborder as first suborder; e.g., Udalfs, Argids, Psamments, Saprists, etc. The second order would be the Great Group Level, second suborder, the Subgroup Level; and the third order, the Family Level with the third suborder, the Series Level.

GEOLOGY/HYDROLOGY

The geologic file included geologic formations as the first order; e.g., Dakota Sandstone, Morrison Formation, Great Smoky Conglomerate. The second order classification is based on rock chemistry. The basic rocks (I) are igneous or metamorphosed igneous; the calcareous (II) are essentially sedimentary carbonate rocks; the carbonaceous (III) are those parent materials high in organic content; the ferruginous (IV) are precipitates, sediments or metasediments unusually red and high in iron; the saline rocks (V) are salt or salty; and the siliceous (VI) are igneous, sedimentary or metamorphic rocks high in quartz or silicic acid. The third order, rock types, are the traditional rocks; e.g., granite, marble, shale, diabase, etc.

The first order and suborder of hydrology is the ecological system and subsystem of the "Interim Classification of Wetlands and Aquatic Habitats of the United States" prepared for the U.S. Fish and Wildlife Service in 1976 which includes the marine, estuarine, riverine, lacustrine and palustrine systems. The first suborder (subsystem) for the marine and estaurine systems is tidal and subtidal; for lacustrine, littoral and profundal; for the riverine, high and low gradient reach and intertidal and subtidal reach; and for the palustrine, no subsystem or suborder.

The water classes, second order hydrology, are based on water chemistry, e.g., fresh water, brackish, subsaline, haline, saline, hyperhaline, hypersaline, acid (bog) and alkaline. No second suborder is recognized.

The water types, third order hydrology, are based on nontidal and tidal flooding or hydroperiod; e.g., nontidal-intermittently flooded, permanently flooded, temporarily flooded, etc.; tidal-irregularly flooded, regularly flooded and subtidal.

TOPOGRAPHY/HYDROGRAPHY

Under the topographic land forms the first order includes named broad features such as basins, beaches, bluffs, hills, plains, ridges; e.g., Okeechobee Plain, Trail Ridge, French Broad Valley. The specific types of each topographic feature (usually based on origin) are treated as second order; e.g., old deltaic plain, old lacustrine basin, fault ridge. The third order, relief, includes the features that are critical as the topographic habitat of the organisms; e.g., crevice, flat, pit, scarp, swale, gentle slope, cleavage.

The hydrographic file includes the named water body or drainage as first order; e.g., Chesapeake Bay, Pamlico Sound, Lake Michigan, Catawba River Drainage. The specific types of each water body or wetland (usually based on origin) are treated as second order; e.g., bar estuary, cirque lake, kettle pond, brown-water stream, lacustine basin, estuarine plain, etc. The third order includes the wetland and aquatic relief features; e.g., bar, bench, fan, flat, reef, riffle, shelf, shoal, etc.

PHYSIOGRAPHY

The physiographic province file is based on Fenneman (1938) with his provinces as first order, region and subprovinces as second order province in this system. The Appalachian Highlands would be an example of a first order "physiographic region," with the Blue Ridge Mountains as an example of a second order "province" and Pisgah Ridge as a third order "subprovince." Subprovinces are distinctive features indicated on topographic maps or hydrographic charts.

CONCLUSIONS

This is an open-ended system that can be done as thoroughly as the time and experience of the investigator will permit. The system can be coded for data banking. Natural areas in a conservation system, or those being proposed, should not be continually investigated for the same thing. The information gathered about the region should be made available to subsequent investigators so that new field data resulting from each inventory can be added to the data bank. All taxa should be documented once, not eliminated by eager biologists collecting in each and every visit to an area. An application of this natural area classification system is presented, in part, in

Appendix A and an ecological characterization of a rare species is given in Appendix B.

1. Any comprehensive natural area inventory should include the total biotic and abiotic (habitat) diversity.

2. Managed areas of different moisture, pH, and texture classes over different parent materials should be conserved within each climatic zone within the province for the perpetuation and study of the native species, particularly pioneer and transient species.

3. Any standardization scheme for natural area inventories should include vegetational (with faunistic components), climatic, pedologic, geologic, hydrologic and topographic data by province.

4. An acceptable standard natural area inventory system should have each character state properly circumscribed for each entry at each hierarchical level so that future studies and analyses will be comparable and correlative.

5. The Natural Area Classification System should be made as compatible as possible with present classification systems for vegetation, climate, soils, geology, hydrology, topography, hydrography and physiographic provinces.

LITERATURE CITED

COWARDIN, LEWIS M. et al. 1976. Interim Classification of Wetlands and Aquatic Habitats of the United States. U.S. Fish and Wildlife Service. 109 pp.

FENNEMAN, N. M. 1938. Physiography of the eastern United States. New York: McGraw-Hill Book Co., Inc.

RADFORD, A.E. et al. 1976. Ecosystematics Lab Manual. Chapel Hill: University of North Carolina Student Stores. 289 pp.

SOIL SURVEY STAFF. 1975. Soil Taxonomy. A Basic System of Soil Classification for Making and Interpreting Soil Surveys. Soil Conservation Service, U.S. Department of Agriculture. Agriculture Handbook No. 436. 754 pp.

GENERAL REMARKS ON APPLICATION OF SYSTEM

This Natural Area Classification System has been or is being used or applied to approximately 150 Natural Areas in the southeastern United States--from Florida and Alabama north to West Virginia and Virginia but mostly in the Carolinas.

The Natural Areas include all 15 vegetation systems; the estuarine, lacustrine, riverine and palustrine aquatic and wetland systems; the alfisols, entisols, histosols, inceptisols, spodosols and ultisols among the soil orders; the ultrabasic, basic, intermediate, acid, calcereous, ferruginous, carbonaceous and salinaceous rock classes; and a wide variety of climatic, topographic and hydrographic features in the Coastal Plain, Piedmont, Blue Ridge, Valley and Ridge and Cumberland and Allegheny Mountain and Plateau Provinces.

Most of the data have been collected and the reports have been made by members of the plant ecosystematics classes at the University of North Carolina at Chapel Hill or by natural area research associates sponsored by the Highlands Biological Station during the summers of 1974 and 1975. These reports will be available to conservationists, ecologists, taxonomists and local, state, regional and federal agencies through a Natural Areas Inventory publication for the southeastern United States within the next 15 months.

The data collected for each report provides the information base for the ecological characterization of each species in the inventory of a Natural Area (see the example in Appendix B).

The summary reports resulting from this work will be similar to the Panther Creek presentation in Appendix A. The second page of the Panther Creek report is one part of a single community write-up for the Panther Creek Natural Area.

APPENDIX A

Panther Creek Natural Area[1]

Stephens County, Georgia; 1.1 miles sw. of Yonah Lake Dam
34° 40'24" N, 83° 21' 07" W, Tugaloo Lake, S.C.-Ga. 7½', 1957
Dahlonega Plateau; Piedmont Province; Appalachian Highlands
720'-1200'; 235 M.-395 M.
300 Acres

Ownership and Administration: Georgia Power and Light Company (20%) Chattahoochee National Forest (80%).
Land Use: Presently second-growth forest without any specific use; slopes previously lumbered, floodplain farmed.
Danger to Integrity: None known except possible damage to fragile slopes by field classes visiting the area.
Publicity Sensitivity: None known at present.

Priority Rating: (1) High degree of national significance, recommended without reservation; (c) Site is in no apparent jeopardy.
Reasons for Priority Rating: Local endemic, *Collinsonia verticillata,* very abundant; rare southeastern endemic magnoliaceous vine, *Schisandra glabra,* abundant; exploited ginseng, *Panax quinquefolium,* very abundant; rare, in Georgia, glade fern, *Athyrium pycnocarpum,* forms a ground cover of more than two acres, unique combination of montane cove hardwood elements with tremendous fern and herb diversity at 1000'; and great diversity of mycetozoans with four unknown species present (pers. com. from Barry Katz).
Recommendations for Management: Area should be maintained as a wilderness preserve.

Data Sources: Wilbur Duncan, University of Georgia, Athens, Ga.; Gladstone McDowell, Asheville, N.C.
Scientific References: None.
Documentation and Authentication: Vascular specimens deposited in the NCU Herbarium. Data collected 25 June 1975 and 30 June 1975.

CLIMATE: Humid Mesothermic; Transition; Wet mesic to dry mesic.
SOILS: Ultisol, Udult; Paleudult (circumneutral clay loam in community analyzed).
GEOLOGY: Brevard Schist; Calcareous-siliceous; Dolomite, phyllite.
TOPOGRAPHY: Plateau; Peneplain; Ravines, sheltered slopes, open slopes, seepages, floodplain, streams.
VEGETATION: Perennial Forb, Angiosperm Forest; Oak-pine Forest, Southern Appalachian Hardwoods, Mixed Perennial Forbs; Chestnut oak - mixed heath, Mixed southern Appalachian Hardwoods - mixed herb.

[1] Contributed by David E. Boufford, Missouri Botanical Garden and Emily W. Wood, University of North Carolina at Chapal Hill.

Angiosperm Forest System
Calcareous Angiosperms

Hardwood Slope
S. Appalachian Hardwood Forest

Cove Hardwood - Mixed Herb
Cove Hardwood Cover

Climate: Humid Mesothermic (Cf); Transition; Mesic

Soil: Ultisol; Udult; Paleudult. Series - .

Topsoil: 3-4", medium brown to black clay loam, high in organic content; pH 7.0-7.1.
Subsoil: 11-20", light brown clay-sand loam; pH 6.2-7.2.
Moisture class, mesic; pH class, circumneutral; texture class, clay loam.

Geology: Brevard Schist; Calcareous Rock; Dolomite.

Topography: Valley; Ravine; Sheltered slopes (steep slopes, 36°, with mostly N-NW aspect).

Canopy: *Liquidambar styraciflua*, ht. 110 ft., DBH 27.1"; most canopy species 12-18" DBH.

Canopy Analysis

Species	I.V.	Rel. Den.	Rel. Dom.	Rel. Freq.
Fagus grandifolia	63.667	18.74%	23.18%	21.747%
Liriodendron tulipifera	54.450	25.00	17.06	17.390
Tilia heterophylla	41.065	15.12	16.75	8.695
Quercus rubra	27.705	6.25	12.76	8.695
Carya cordiformis	20.267	6.25	5.62	8.695
Fraxinus americana	19.085	6.25	4.14	8.695
Quercus prinus	18.147	3.13	10.67	4.347
Ulmus rubra	16.375	6.25	1.43	8.695
Aesculus octandra	12.017	6.25	1.42	4.347
Liquidambar styraciflua	11.617	3.13	4.14	4.347
Halesia carolina	10.307	3.13	2.83	4.347

Based on 8 quarterpoints; d = 21.9 ft.; 91 individuals/acre

Also Present: *Acer rubrum, Carya glabra, Carya tomentosa, Juglans cinerea, Magnolia acuminata, Magnolia fraseri, Nyssa sylvatica, Prunus serotina, Quercus alba, Quercus nigra, Quercus phellos, Tsuga canadensis.*

APPENDIX B

ECOLOGICAL CHARACTERIZATION of *Gaylussacia brachycera* (Michx.) Gray
A rare, localized evergreen huckleberry from Congaree Creek, Lexington Co., S.C.
Mesothermic, lower austral, wet-mesic; sandy, siliceous, thermic, typic haplaquodic; riverine, high-gradient, acid, saturated; seepage slope species.

A METHOD FOR EVALUATING NATIONAL PARKS AND NATURAL AREAS[1]

George A. Petrides[2]

Comments frequently are heard that some particular national park or nature reserve either is or is not "up to international standard." But international standards for such areas have not been firmly established. The qualities of these tracts are still largely matters of personal evaluation and judgment. This paper, with its appended checklist, is an effort toward the establishment of suitable standards for national parks and reserves. It is based on studies in national parks and nature reserves in Kenya, Uganda, Tanzania, South Africa, Rhodesia, Zambia, Nepal, India, Brazil, Argentina, Canada, the United States and other countries.

WHAT IS A NATIONAL PARK?

A national park may be defined as an area of *natural* landscapes (or seascapes) which contain the vegetation and animal life native to the region and which is legally dedicated to the *permanent* preservation of nature and wilderness for the enjoyment and inspiration of the public.

National parks as natural areas established for permanent preservation is a concept which has spread around the world. Credit for the national park idea usually is given to the Washburne party of Americans who planned for the preservation of the Yellowstone region in 1872. Yet even before the birth of Christ such a visionary as the Emperor Asoka of India (Asoka 1877) suggested the establishment of similar areas.

National parks comprise a distinct form of land (and water) use. Though these are natural tracts, they are artifacts of man which serve as living museums, displaying native floras and faunas actively reacting with their controlling environmental forces. They yield scientific, historic, recreational, and economic benefits to mankind but also, and most importantly, they have cultural values comparable to those of libraries, art galleries, cathedrals and universities.

Despite the primary objective to preserve a national park as a primitively wild and natural area, there is a parallel and equally significant need to enable, and indeed to encourage, the proper use of the area by visitors. The principal benefits of national parks are realized only when they are utilized by the public. Indeed, visitor use and tourist economics can be said to be the essential elements which save wild animals and their habitats from being overwhelmed and destroyed by other forms of resource use.

Most often, natural reserves are "islands" of wild biota which exist amidst "seas" of contrary land (or water) use. Like the flora and fauna of real islands, the living species of national parks, singly or severally, are in considerable danger of being overcome and possibly eliminated by a catastrophic environmental change which overwhelms their relatively small and usually isolated preserves.

Tourism finances the scientific research and physical protection which enables intelligent forecasts of impending dangers and permits adequate management and physical protection.

GENERAL STATUS OF THE BIOTA

The quality of a national park or natural reserve is directly related to the extent to which wild conditions prevail. The combined need to maintain natural values and yet to supply adequate public facilities comprises the continuing dilemma of national park management.

National parks and similar reserves may be inadequate if they fail to contain the plants and animals indigenous to the region. Furthermore, all species should be in their natural abundance and in essentially undisturbed environments.

Preferably, the biotic communities present should be representative of a particular biome. Yet some species may have become extinct or be unnaturally rare, while others exotic to the region may have invaded the native biotic communities.

Some animals species may have become overabundant, damaging their vegetative habitats and affecting other species in the community. Because of this danger, it may be desirable in a few portions of the reserve to keep species which show a tendency toward unnatural abundance (herbivores, almost invariably) at somewhat below-normal densities in order to insure the survival of some plants or animals which otherwise would be adversely affected. As suggested in earlier papers (see Petrides 1963, 1974), under present day conditions most, and perhaps all, wild areas now require at least some management in order to preserve their wilderness character. Yet management in excess of national park needs is wrong.

In many cases the size of a national park is a major factor determining the maintenance of wild conditions. Ideally, a nature reserve should be sufficiently large to include the annual movements of its most wide-ranging inhabitants. Yet for some migratory animals, this may be infeasible on any one reserve. It is important, nevertheless, to evaluate the extent to which the goal of adequate size is achieved.

LAND USE CONFLICTS

In an ideal national park there should be no farming, no livestock grazing, no lumbering, no mining, no hunting, no fishing and no building of dams or other obtrusive structures. Equally, there should be no hay cutting, no grazing of pack- or riding-animals, no gathering of firewood or thatching grass, and no prospecting for mineral or other resources. All of these practices are condoned in national parks in some countries (sport fishing, for example, is an established

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[1]Based on notes presented to the conference on Environmental Sciences in the Developing Countries, UN Environmental Programme, Nairobi, Kenya, February 1974.

[2]Department of Fisheries and Wildlife, and Zoology, Michigan State University, East Lansing.

practice in the United States); nevertheless, under ideal circumstances they are to be avoided. Most often they begin as "temporary" practices or are restricted to certain areas. But in time such activities become established as traditional procedures; almost inevitably they increase beyond control.

The occurrence of areas within national park boundaries which are devoted to unnatural land uses is a matter of conflict. Any permanent settlement within park boundaries threatens park values. Private ownership even of vacant lands, offers a threat to area permanence and should be overcome.

VISITOR FACILITIES

In terms of visitor access, the quality of the area is a function of the degree to which tourists and public facilities are unobtrusive. Ideally air strips and boat docks as well as most buildings and other structures should be placed outside park boundaries. Where this is not feasible, visitor amenities in national parks should be somewhat primitive and in keeping with the presumed desire of the public for a wilderness or near-wilderness experience. In practice, however, many visitors insist on housing and eating facilities which approach the luxurious. Yet, certainly extreme development of tourists accomodations should be avoided. Where structures must be built, then architecture characteristic of native regional structures is desirable.

Except where dangerous animals prevent, the effort should be made also to attract visitors to the trails either on foot or on the horses, elephants, camels or other riding animals of the region. Even in Africa, foot safaries are being developed in some areas under ranger supervision. Especially when large carnivores or their signs are seen, these provide memorable experiences.

Where trail travel becomes common, excessive trampling, trail short-cuts, and littering may cause problems. Boating and rafting facilities also often can become crowded with portages and landing places subject to overuse. Such overuse may have to be controlled through quota limitations on the number of people using critical trails and areas.

In national parks and nature reserves almost everywhere, demands are made increasingly for more roads. Not only is the overdevelopment of roads a constant threat, there often are related appeals for house trailer parks, garages and repair facilities, and similar developments. Public education and park zoning probably are the only hopes to confine road developments to a moderate and reasonable level.

Begging by park animals is another unnatural condition which often develops in national parks and nature reserves. Visitors think that such animals are tame and often place themselves in physical danger when they approach them. Though people should be discouraged from feeding begging animals, there may be some benefits in bringing visitors closer to nature, even if the begging animal is a doubtful representative of his kind. These benefits of animal beggars must be weighed carefully against the accompanying dangers and detriments. A decision to permit or to control begging should be made before it becomes a widespread practice in a reserve. In most instances, individual begging animals should not be regarded favorably.

Educational signs, displays and museums enabl park visitors to derive maximum benefits from their tours of the area. Yet in excess, they to detract from an atmosphere of wild nature. As with all human intrusions into the natural surroundings, careful design and limited applicatio are necessary.

WILDLIFE POLICIES

National parks, by definition, require that both wild flora and fauna be maintained at optim levels under natural conditions. No plant or animal species is to be allowed to become either unnaturally much-reduced in numbers or overabundant. Wildlife must be accessible to the visito only to the extent that he is willing to experience the normal environmental conditions under which the species lives.

Wildlife problems in national parks often are some of the most difficult to resolve. Should fire prevention be practiced? Or should fires b allowed to burn in order to approximate their natural occurrence? Should wild herbivores be allowed to increase and possibly to overgraze or overbrowse the vegetation? Or is animal control by park authorities to be forbidden in nature reserves? Should park borders be fenced to prevent damage to adjacent crops or livestock? Should more watering places or more salt station be established to enable the better utilization of some wildlife rangelands? Or will too many dam or wells lead to undesirable vegetative chan ges in the absence of herbivore control? Should there be interior fences or fenced plots to provide protected check area and to shelter certain forage plants or prey animals against the specie which normally feed on them?

Such questions have caused frequent disputes among nature conservationists in the past. In general, however, it seems now to be recognized generally that neither fire nor fire control, neither animal overabundance nor animal control, neither fencing nor its lack, neither the provision of dams nor the failure to provide additional water, should be considered as an inviola or invariable policy. It has finally become accepted, it is believed, that the particular needs of a local area may require a particular management solution which may not be the same as that required elsewhere.

THE PROPER BALANCE

In national parks and natural area preservati it is now generally agreed that a "hands off" policy of non-management is not always the best policy. Though probably such a procedure should pursued until there is evident need that management is required, the decision to manage must be the result of careful scientific appraisal. It is desirable, however, that such study not be so prolonged that the investigation in itself becom a problem. Decisions to "manage" or "not to man age" nature probably should be made with referen mainly to specific portions or zones of the national park involved. There are few, if any, policies which can be applied blindly over widespread areas.

National parks, no matter how large, are subject to destruction by natural forces as well as by encroachment and by overuse. Once destroyed, they are not likely to be restored within the foreseeable future. Both the time required for nature to heal its wounds and the pressure on th area for other uses by exploding human populatio will tend to prevent the restoration of natural units once they are seriously damaged. It is fo

FORM 1. EVALUATION OF NATURAL AREA

Name of area Wankie Natl Park, Rhodesia Date 16-19 July 1969

Administering agency Dept. N. Pks & Wildl. Mgt. Person interviewed: _____

Size 5630 sq. mi Year established _____

Number of visitors previous year _____ Visitor numbers restricted? No

Principal cultural values:

Botanical 10 of Rhodesia's 30 major types Zoological 50 spp. large mammals Geological Near Victoria Falls

Archeological _____ Historic _____

Status of indigenous biota:

Plants locally damaged by herbivores; fire effects uncertain

Herbivores outstanding sable, roan, & eland populations

Carnivores lions common; main area in Rh. for cheetahs, wild dogs, brown hyenas, bat-e.fox

Fishes _____

Communities trees & shrubs locally damaged by elephants

Extinct Plants _____ Fishes _____

Birds _____ Mammals _____

Unnaturally rare species gemsbok, red hartebeest, oribi, tsese bee, bl. rhino, wh. rhino, wild dog, cheetah

Overbundant native species elephant & locally buffalo, wildebeest, zebra, impala, warthog, giraffe, spring hare

Exotic invading species _____

Low-density wildlife areas (safety) none

Provision of (Prevention of excessive) amenities:

Roads	+	(+)	Picnic sites	+	(++)	Boating facilities	o (o)
Trails	o	(o)	Riding horses	o	(o)	Garage Facilities	- (+)
Camping	—	(++)	Sports grounds	o	(o)	Wilderness trails	o (o)
Hotels	++	(++)	Amusements	o	(o)	Caravan and trailer parks	o (o)
Airstrips	+	(-)	Tour Buses	+	(-)		

Effective prevention of adverse land use (through both legal prohibition and law enforcement:)

Lumbering timber formerly cut by Forestry Dept

Livestock grazing rare

Pack-animal foraging none

Farming none

Haying none

Settlement visitor lodges only

Hunting Opposed. "Like a rock concert in a cathedral" - warden

Fishing weirs on streams coming into park from Botswana

Trapping none

Prospecting none

Mining none - but large coal deposits nearby

Storage and power dams none

Trail short-cuts none

Firewood gathering slight, local

Thatching-grass gathering minor local

Litter minor

Vegetative trampling by visitors negligible

Wild-animal begging none

Private-land enclaves none

Provision of (Prevention of excessive) management procedures:

Predator control Before 1930, w. dogs, hyenas & leopards shot. Not now

Herbivore control Locally by staff: elephants, wildebeest, zebra, impala, buffalo

Pet control Good

Burning program Needs review

Firebreaks Roads & railway only

Fire control Central natural area planned for protection

Erosion control Needed around Sinamatella & Robin's camps

Boundary game fences On southeast & northeast now

Interior game fences None needed

Poaching control Good

Ranger posts Adequate to good

Bore holes Inadequate for large elephant pop. Water controlled to decrease grazing locally.

Dams Water shortages in northern & eastern sections. Dams attract birds

Salt stations None?

Display museums None?

Specimen collections None

Educational signs Few; more needed

Naturalist lectures Needed

Naturalist trips "

Wildlife exclosures Needed to determine grazing effects. A few now protect trees from elephants

Ecological research Need data on reciprocal effects of fire, waterholes & erosion on veg. & wildlife

Historical records

Adequate financing Needed for scientific & educational programs

Area of adequate size Kazuma Pan area should be annexed

Visitor-number limitations Limited to 240 beds. 5th camp to be built. Hotel planned outside park

Professional staff: Administrative Not professional Scientific None

Educational None Enforcement Adequate?

Important native biotic communities and species not included; other characteristic features of region which are lacking in the area: Kazuma Pan (Depression) has unique arid-zone vegetation, rare ungulates, & seasonal bird flocks

Principal needs to fulfill area objectives:

Ungulate control

Improved burning policy

Kazuma Pan extension

Principal threats to area survival (biological, land use, political, etc.).

Invasions of elephants & wildebeest from Botswana during droughts

Spread of foot & mouth disease by eland migrating onto cattle ranches in the east

General notes:

One of Africa's most important national parks & nature reserves

++ = yes, good. + = some, fair - = few, poor -- = no, none o = not represented

Nairobi, Kenya
February, 1974

George A. Petrides, Professor
Department of Fisheries and Wildlife
Michigan State University
East Lansing, Michigan, USA

this reason that management must be undertaken where necessary. Even then, however, it should be applied only to the extent required to preserve natural conditions.

A SUGGESTED CHECKLIST

A tentative checklist to enable the evaluation of a natural park or other natural reserve is given here (Form 1). The evaluation shown is the result of an actual field inspection made some years ago. It is given only as an example; conditions in that area may well have changed since it was compiled.

In undertaking an evaluation using this form, the items of area size, principal values, status of native species, and prevention of adverse land use are fairly straightforward, it is believed, in their ease of appraisal. No one without extensive technical training and field experience, however, probably should attempt to evaluate whether or not tourist amenities or management procedures are applied to an adequate but not to an excessive degree. Doubtless not all observers, even with the best of backgrounds, would respond in an identical manner.

This effort at standardizing procedures attempts to enumerate items of importance in natural area evaluation. It is hoped that this scheme will encourage the further development of methods for evaluating the status of national park, nature reserve, and tourism resources.

LITERATURE CITED

ASOKA, (EMPORER). 1877. Inscriptions of Asoka. Govt. Printing Office, Calcutta. iii + 141 pp.

PETRIDES, GEORGE A. 1963. Ecological research as a basis for wildlife management in Africa. IUCN Publ. New Series No. 1, Morges, Switzerland: 284-293.

_____. 1974. The overgrazing cycle as a characteristic of tropical savannas and grasslands in Africa. Proc. 1st Internat. Cong. Ecol. (Hague): 86-91.

THE HALEAKALA CRATER ECOSYSTEM[1]

Clifford W. Smith[2]

INTRODUCTION

The first recorded ascent of Haleakala took lace in 1828. The first scientific study was ade in 1841 by a party from the Wilkes Expedition. rom that time on the area has attracted scien- ists and tourists alike, due to the fame of the cenery and the plants, particularly the silver- word.

By the turn of the century, most of the endemic lowering plants and birds had been described and heir extinction was becoming a matter of some oncern to biologists around the world, The biol- gy of other groups of the area is not as well nderstood as that of the flowering plants and irds. Preliminary studies of the insects were onducted by Perkins (1896,1899-1910) who described many taxa unique to Haleakala. Later, Swezey and Degener (1928) discussed the insect flora of the silversword and greensword, many of the species described being unique to Haleakala. More re- cently, Kobayashi (1974) has studied the impact of these insects on the fecundity of the silver- sword. Beardsley (1964, 1971) has also reported many new species of insects from Haleakala. There are very few reports that deal with any other groups, e.g. mosses, lichens, etc.

The first guide to Haleakala Crater was an ac- count of the legends, geology, vascular plants, birds, mammals, and insects of the then Haleakala Section of Hawaii National Park (Ruhle 1959). It is still the only comprehensive compendium on the biology of the area.

No ecological studies were made until ten years ago. Yocum (1967), in his report on feral goats within the Crater, assessed the effects of the grazing pressure of these animals on the vegeta- tion. Larson (1969), in an early Resource Manage- ment Plan for the Park, identified four major vegetation-types: marginal rainforest, scrub, scrub-savannah, and barren areas. Forehand (1970), Henrickson (1971), Vogl (1971), and Vogl and Henrickson (1971) have all studied various aspects of the *Deschampsia* grasslands on the outer north face of the Crater along Kalapawili Ridge. Koba- yashi (1973) has conducted an intensive autoeco- logical study on the silversword, *Argyroxiphium sandwicense* DC.

A high degree of endemism is typical of the fauna and flora of oceanic islands (Carlquist 1965). This biota has generally evolved in the absence of many of the biological pressures inher- ent in continental ecosystems. Thus, endemic species are very vulnerable when confronted by highly aggressive, exotic organisms no longer con- trolled as in their natural ecosystems. Resource managers are therefore faced with enormous problems when trying to maintain oceanic ecosystems which have been invaded by exotic species (McEachern and Towle 1972). In parts of Haleakala National Park the problem is further aggravated by the fragile nature of alpine ecosystems. These communities recover very slowly even after relatively minor disturbances (Billings 1973).

The bioecological survey was initiated to pro- vide information on the species present, their loca- tion and abundance. It will also include an anal- ysis of the ecosystems present and a vegetation map with supporting information.

DESCRIPTION OF THE AREA

Haleakala National Park is located on the island of Maui, the second largest island in the Hawaiian Archipelago. The National Park is subdivided into two districts: the Crater District, the area under discussion; and the Kipahulu Valley District. The Crater District (Fig. 1) includes all areas of the National Park west of a line from Pohaku Palaha, Kuiki, and the Koa Tree on the eastern side of Kaupo.

The Crater District encompasses land reaching from 1,250 to 3,300 m in elevation. Since most of the Crater is above the inversion layer and also protected by the Crater walls, the average annual rainfall is quite low. In most areas, it does not exceed 100 mm/yr. Most of the rainfall comes dur- ing a few southerly storms during the winter. How- ever, along the eastern rim of the crater where clouds tend to be blown up much higher by the strong tradewinds, the average can reach 380-500 mm/yr (Tagliaferro 1959; Yocum 1967). The change in average precipitation between these two areas is quite abrupt. In the Paliku area and just outside the National Park in the Ko'olau Gap, the distance between areas experiencing the highest and lowest annual rainfall is no more than one mile. The amount of cloud cover varies from frequent morning and afternoon overcast conditions along the east- ern and northern rims of the Crater to rarely over- cast conditions at the summit. The majority of the Crater District is quite arid due to infrequent rainfall and high isolation.

The average monthly temperatures vary from ap- proximately 0°C in the winter to 15°C in the sum- mer at the summit and 5 to 24°C respectively at 1,250 m. Frost is common at night at the summit and rare at 1,250 m. Snow falls during most winters down to about 2,600 m.

There are three distinctive substrate types within the Crater District--first, a deep, rela- tively porous substrate that consists of either ash, cinder, or an alluvial deposit; second, rela- tively recent "aa" or pahoehoe lava flows. These two substrates cover much of the Crater floor and the Ko'olau and Kaupo Gaps. The third type, very stony land with rocks covering more than 50 per- cent of the ground, is found in areas other than the Crater floor. There is no true soil formed except below 2,300 m where alluvia of fine ash have accumulated in isolated pockets, and at all alti- tudes where the rainfall is above 250 mm/yr.

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[1]Contribution Number 011/7 CPSU University of Hawaii. This work is a greatly abbreviated ver- sion of the work of Drs. John Beardsley, Frank Howarth, Sheila Conant, and William J. Hoe, Tissa and Ruki Herat, Robin Rice, Glenn Teves, Lani Stemmermann, Paul Higashino, Robert Burkhart, H. Eddie Smith, and myself. This study was funded under the National Park Service, contract number CX 8000 6 0031.

[2]Department of Botany, University of Hawaii, Honolulu 96822.

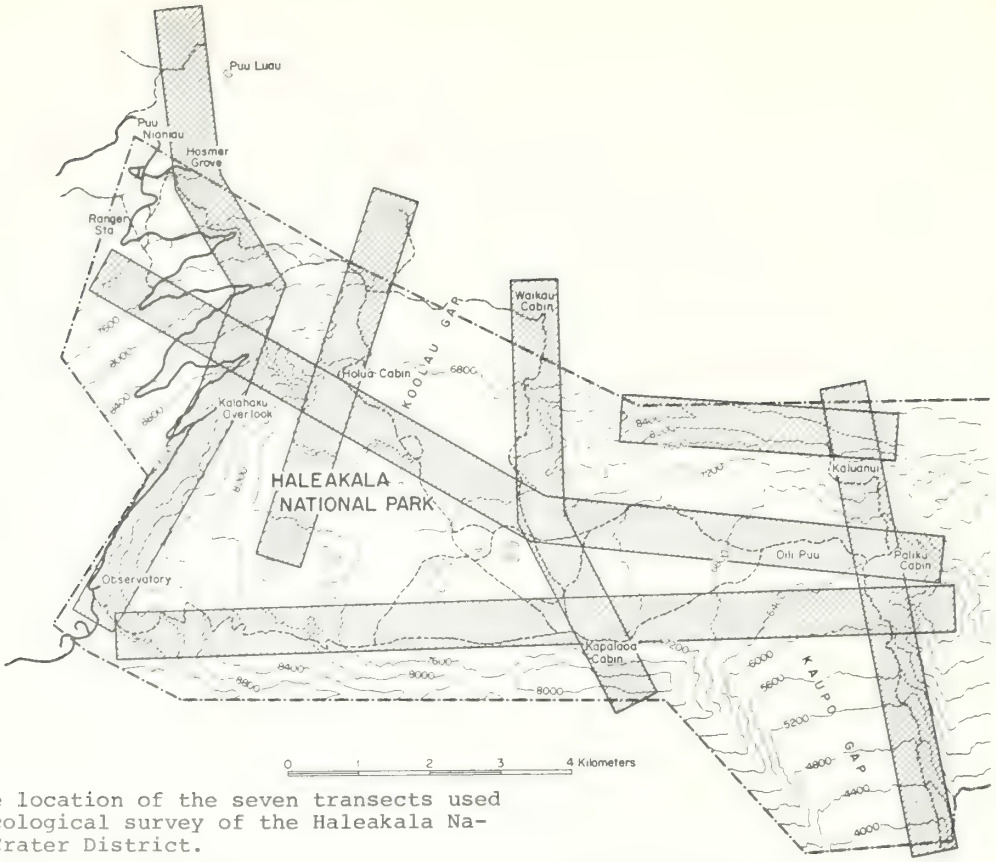

FIGURE 1. The location of the seven transects used in this bioecological survey of the Haleakala National Park Crater District.

METHODS AND MATERIALS

The principal method of study has been to work along seven transects (Fig. 1)--four in a north-south orientation: 1) Pu'u Nianiau to Red Hill, 2) 'Ainahou to beyond Holua Cabin, 3) Kapalaoa through Pu'u Maile to Waikau, 4) the Koa Tree through Paliku to the top of Kalapawili Ridge; the remaining three in an east-west orientation: 5) along Kalapawili Ridge, 6) Paliku to Red Hill, 7) Paliku to Kalahaku. Each transect was sampled approximately every thousand-foot change in elevation or every mile, whichever was most appropriate. At each site all species present were recorded and an analysis of the vegetation type was made using the Braun-Blanquet method as modified by Mueller-Dombois and Ellenberg (1974).

At each study site an area of about one acre was chosen which had a representative sample of the vegetation. This is a highly subjective choice and it is fully realized that it can introduce a considerable bias into the evaluation. However, this work will not produce the definitive statements on the vegetation of Haleakala Crater. Rather, it will provide some hypotheses that will be tested in the vegetation mapping program recently started. If the study area was in a region where there was obviously more than one vegetation type present, each community was studied separately.

The species distribution maps were plotted using the computer programs EZPLOT (Bridges 1973) and SPLOT (Bridges 1976). A grid system has been established for the Crater District and all known points of presence or absence for a particular species are then entered into a plotting program using a very simple format. A contour plot is then produced which shows where the species is known to be present and absent (Fig. 2). Between these points, contours of previously determined intervals are plotted. The contours represent the various levels of confidence of finding the species in that locality. This information can then be correlated with vegetation, geological, soil, rainfall, and other information also stored in the computer data bank. Any correlations can then be rapidly checked by field work and detailed bioecological information given to the resource managers for incorporation into management programs.

RESULTS AND DISCUSSION

Compared with an area such as Hawaii Volcanoes National Park, Haleakala Crater has received little attention. This is particularly surprising considering the variety of ecosystems represented in such a small area and the unique endemic fauna and flora. For example, there are several plants and animals unique to Haleakala: *Geranium arboreum* Gray, an unusual arborescent geranium; *Geranium multiflorum* Gray; *Artemisia mauiensis* (Gray) Skottsb.; *Santalum haleakalae* Hbd.; *Stenogyne crenata* Gray; and depending on your taxonomy you may or may not consider the Haleakala silversword as endemic to the Crater. There are 14 species of moss, 11 species of lichen, and 33 insect species present in the Crater which are unique to Haleakala. Among the insects unique to Haleakala are *Hodegia apetala* Walsingham, which is quite unusual in that both sexes are flightless; *Megalotica holombra* (Meyrick), an unusual day flying moth; *Agrostis xiphias* Meyrick; and *Barypristus rupicola* (Blackburn). This listing is by no means complete since it does not include species from Kipahulu or other areas of Haleakala. Also, work on these groups is still in progress.

During the course of this study, species and organisms newly recorded in the Hawaiian Islands have been the rule rather than the exception. A number of new species are also being described. Most of these species have simply been overlooked in the past. On the other hand, many of the groups have been collected by specialists with only a day or two to work in the area. Their natural

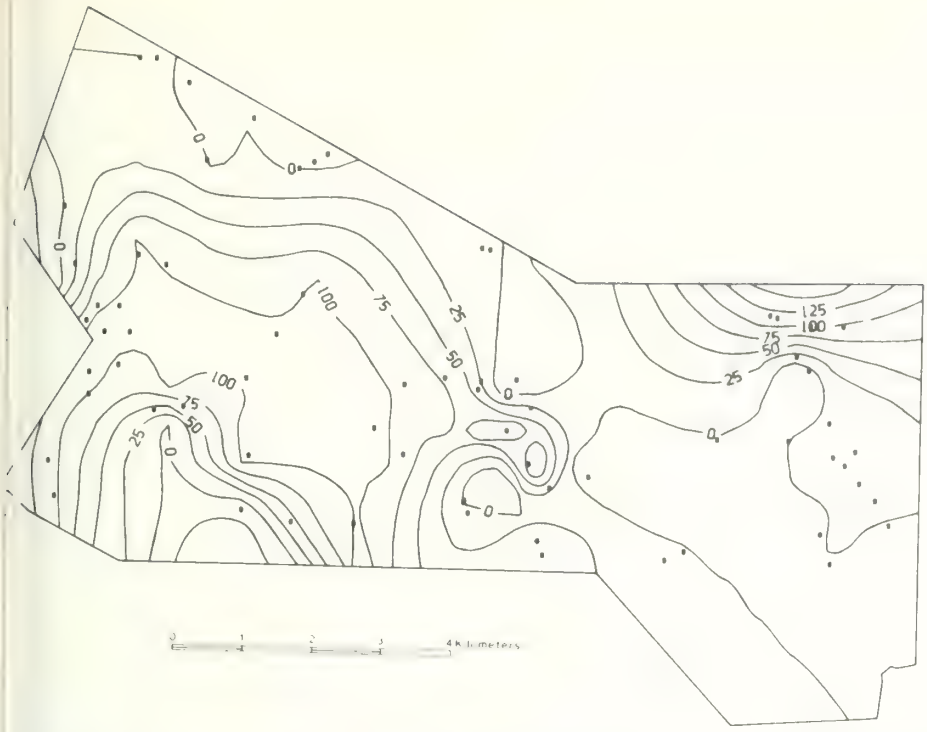

FIGURE 2. SPLOT contour plot of the distribution of *Argyroxiphium sandwicense* in Haleakala National Park Crater District. Each presence/absence record point is represented by the oblong mark.

nclination was to work areas of known interest or o cover as much area as possible working along he established trails. There are many isolated ockets of relatively undisturbed vegetation, ost of which are remote from the trails. The ntensive systematic sampling technique used in his study has shown that many species are extremely localized in their distribution. For example, as far as we know to date, *Andreaea rupestris* Hedw. is found only in the Kapalaoa Cabin area and along the Kuiki Trail; two species of *Tortula* are found only in the Pu'u Mamane-Namana o ke Akua area. There are many other examples, all of which serve to emphasize the fact that the Haleakala Crater area has been studied in a very superficial manner at best.

A serious problem for any study in Haleakala National Park is that the use of the Crater and surrounding areas as cattle ranch land during the past 100 years has seriously disrupted the native ecosystem. Until the early 1950's cattle grazed within the Crater. In fact, the National Park Service still does not have the grazing rights to certain areas though the rights have not been exercised for 25 years or more. Apart from cattle grazing, some areas such as the Kaupo Gap were deliberately burned in an attempt to improve the pasture. The devastation caused by such activities is very difficult to assess now. However, it is suspected that the eastern portion of the Crater, in particular, supported a very different vegetation compared to today's scrub. It is thought that previously there were extensive areas of open dryland forest of uncertain composition. Scattered remnants of *Pittosporum confertiflorum* Gray, *Santalum haleakalae, Sophora chrysophylla* (Salisb.) Seem., *Dodonaea eriocarpa* Sm., etc., suggest that these species were major components of the forest interspersed with *Vaccinium*, principally *V. reticulatum* Sm., and *Styphelia tameiameiae* (Cham.) F. Muell. The damage done by cattle and fire, and the continuous suppression of regeneration by goats over the past 150 years, have resulted in the establishment of a *Styphelia-Vaccinium* scrub with or without *Sophora* depending on the location.

The damage done by feral pigs is relatively recent and generally confined to the peripheral areas of the Crater. Pigs come up into the Park from the surrounding forest to forage. The impact that they can have is amply demonstrated on Kuiki where the *Deschampsia*-grassland which once dominated the area is now gone. The uprooting by pigs resulted in very severe erosion and the top soil was washed away exposing the underlying rocks. Plants that become established in between the rocks are trimmed back by goats. The rocks are now covered by lichens dominated by *Stereocaulon ramulosum* (Sw.) Rausch.

In contrast to Larson (1969), six major vegetation types are recognized within the Crater:

Tussock Grassland. This vegetation type is normally confined to alluvial deposits, the ash aggregates at the center of cinder cones, and to ash deposits at high elevations where the rainfall exceeds 250 mm/yr. The controlling factors appear to be deep layers of porous ash or cinder and an adequate supply of water. In the pristine condition the species diversity is low. The dominant species is *Deschampsia australis* f. *haleakalaensis* (Skottsb.) Skottsb., but when disturbed by pigs, horses, or humans, the tussock grasses, *Holcus lanatus* L. and *Dactylis glomerata* L., together with *Hypochaeris radicata* L., invade and frequently predominate in the area.

Rainforest. This community is found in the Crater at Paliku only, particularly on the cliffs leading up to Kuiki. The rainfall in this area is high (400-500 mm/yr) and the community is frequently bathed in cloud. It is dominated by *Metrosideros collina* var. *polymorpha* (Gaud.) Rock and some *Cheirodendron trigynum* (Gaud.) Heller, with a high diversity of understory plants dominated by *Sadleria cyatheoides* Kaulf. In the shaded, deeply eroded gullies, *Metrosideros* is absent and replaced by a mixture of *Pelea* sp., *Ilex anomala* H. & A., *Myrsine lessertiana* A. DC. and *Broussaisia arguta* Gaud. There are very few weeds in this vegetation type which is indicative of little or no disturbance by man or feral animals.

Koa Forest (now Koa Savannah). Though only represented by remnants, a major forest of Gray probably existed on the eastern flank of the Kaupo Gap. The rainfall is intermediate between

that at Paliku and the general Crater area. No regeneration of the community occurs because goats which occur here in very high numbers graze off all seedlings and suckers. The areas between the trees support a ground cover of introduced weeds, predominately *Holcus lanatus* and *Eupatorium adenophorum* Spreng.

Scrub. This is the dominant vegetation type inside the crater and around the higher outer regions of Haleakala. However, under this heading there are two different communities: one a climax community characteristic of the drier and higher elevations (i.e., above 2,300 m), and the other an arrested seral stage of the dryland forest climax which is found below 2,300 m particularly on the eastern side of the Kaupo Gap and outer northern slopes of the Crater.

Scrub--Climax Community. This community consists of *Vaccinium, Styphelia, Coprosma montana* Hbd., *C. ernodeoides* Gray, and *Pteridium aquilinum* var.*decompositum* (Gaud.) Tryon, with or without *Sophora chrysophylla*. It occurs in the drier regions of the Crater and generally from 2,300 m to 3,000 m. It occurs at lower elevations in very dry climates, e.g., west Kaupo Gap and the Ko'olau Gap.

Scrub--Seral Stage. This community occurs below 2,300 m. From remnants scattered throughout the Crater, particularly the Paliku and eastern side of Kaupo regions, it is thought that the climax community would contain *Coprosma montana, Euphorbia celastroides* Boiss. in A. DC., *Dodonaea eriocarpa, Myrsine lessertiana, Pittosporum confertiflorum, Santalum haleakalae,* and *Sophora chrysophylla,* with *Coprosma ernodeoides, Osteomeles anthyllidifolia* Lindl., *Styphelia tameiameiae,* and *Vaccinium reticulatum* forming an understory.

Barren Areas. In this community the vegetation cover is less than 20 percent and the species diversity is low. At high elevations (above 3,000 m) the most common species are *Agrostis sandwicensis* Hbd., *Argyroxiphium sandwicense* DC., *Hypochaeris radicata, Raillardia menziesii* Gray, *Tetramolopium humile* (Gray) Hbd., and *Trisetum glomeratum* (Kunth) Trin. in Steud. At lower elevations, where the rainfall is low and the substratum consists of deep layers of porous ash with occasional rocky outcrops, a similar community exists. *Pteridium aquilinum* var. *decompositum* and *Silene struthioloides* Gray are also common at these lower elevations.

All of these areas except the rainforest are severely disturbed by goats either from grazing or substrate disturbance. Pigs on the other hand have a significant impact in the rainforest and adjacent scrub/dryland forest areas. Even when the pressure from feral pigs and goats is removed, the dramatic revegetation as seen in the coastal lowlands of Hawaii Volcanoes National Park following goat population control will not be realized (Mueller-Dombois and Spatz 1975). Current exclosure studies in Haleakala Crater indicate that the rate of recovery will be extremely slow. This is not surprising. The work of Billings (1973) and many others have shown that arctic and alpine ecosystems regenerate very slowly. The sooner the feral herbivores are removed, the better. However, to conclude on a somewhat dismal note, deer are seen in the Kaupo Gap with increasing frequency in the lower and mid-elevations.

LITERATURE CITED

BEARDSLEY, J.W. 1964. A new genus and species o Pseudococcidae from Haleakala, Maui. Proc. Ha Ent. Soc., 18:365-368.

BEARDSLEY, J.W. 1971. New genera and species o Hawaiian Pseudococcidae (Homoptera). Proc. Haw. Ent. Soc. 21:41-58.

BILLINGS, W.D. 1973. Arctic and alpine vegetations: similarities, differences, and suscept bility to disturbance. BioScience 23:697-704

BRIDGES, K.W. 1973. EZPLOT: a computer program which allows easy use of a line plotter. US/ Island Ecosystems IRP Tech. Rep. 28. 39 pp.

BRIDGES, K.W., and R.E. BECKER. 1976. SPLOT: a input processing program for users of CONTOUR and PLOT3D. Computer Programs for Ecological Data Processing, Tech. Rep. 2. 86 pp. (Univ. Hawaii, Dept. of Botany).

CARLQUIST, S. 1965. Island life. Natural Hist Press, Garden City, N.Y. 457 pp.

FOREHAND, S. 1970. The phytosociology of an alpine tussock grassland on East Maui, Hawaii. M.A. Thesis. Calif. State Coll. at Los Angel 93 pp.

HENRICKSON, J. 1971. Vascular flora of the nor east outer slopes of Haleakala Crater, East Maui, Hawaii. Contr. Nature Conservancy 7, 14 pp.

KOBAYASHI, H.K. 1973. Ecology of the silversw *Argyroxiphium sandwicense* DC. (Compositae) Haleakala Crater, Maui. Ph.D. Thesis. Univ. Hawaii. 91 pp.

KOBAYASHI, H.K. 1974. Preliminary investigatio on insects affecting the reproductive stage o the silversword (*Argyroxiphium sandwicense* DC Compositae, Haleakala Crater, Maui, Hawaii. Proc. Haw. Ent. Soc. 21:397-402.

LARSON, J.W. 1969. Haleakala National Park Nat ral Sciences Research Plan. US Dept. of Inte ior, Natl. Park Service, Washington, D.C.

MCEACHERN, J., and E.L. TOWLE. 1972. Resource management programs for oceanic islands. Tra 37th N. Amer. Wild. Conf., 145-159.

MUELLER-DOMBOIS, D., and H. ELLENBERG. 1974. A and methods of vegetation ecology. J. Wiley Sons, New York. 547 pp.

MUELLER-DOMBOIS, D., and G. SPATZ. 1975. The i fluence of feral goats on the lowland vegetat in Hawaii Volcanoes National Park. Phytocoenologia, 3:1-29.

PERKINS, R.C.L. 1896. A collecting trip on Hal kala, Maui, Sandwich Islands. Ent. Monthly Magazine 32:190-195.

PERKINS, R.C.L. 1899-1910. In D. Sharp, ed. *Fauna Hawaiiensis*. Cambridge Univ. Press.

PRICE, S. 1973. Climate. Pages 53-60 in R.W. Armstrong, ed. Atlas of Hawaii. University Press of Hawaii, Honolulu. 222 pp.

RUHLE, G.C. 1959. Hawaii National Park: A guid for the Haleakala Section, Island of Maui, Hawaii. Haw. Nat. Hist. Assn. 94 pp.

SWEZEY, O.H., and O. DEGENER. 1928. Insect fau of the silversword and greensword. Proc. Haw Ent. Soc. 7:183-185.

TAGLIAFERRO, W.J. 1959. Rainfall of the Hawaii Islands. Hawaii Water Authority, Honolulu.

VOGL, R.J. 1971. General ecology of northeast outer slopes of Haleakala Crater, East Maui, Hawaii. Contr. Nature Conservancy 6. 8 pp.

VOGL, R.J., and J. HENRICKSON. 1971. Vegetatio of an alpine bog on East Maui, Hawaii. Pacif Science 25:475-483.

YOCUM, C.F. 1967. Ecology of feral goats in Ha kala National Park, Maui, Hawaii. Amer. Mid. Naturalist 77:418-451

BASELINE ECOLOGICAL STUDIES AND PLANNING IN APOSTLE ISLANDS NATIONAL LAKESHORE

R.T. Brown, R.M. Linn, W.L. Kowalski, W.C. Larsen and R.A. Schulz[1]

On September 26, 1970, the enabling legislation to establish Apostle Islands National Lakeshore was passed. With this accomplished, the planning and development must take place. The best planning and development requires as much information as can be obtained within restrictions imposed by factors concerned with budgets, time and knowledge of investigators. The project here described has two aims:

1. Accumulating a data base of ecological information including a knowledge of soil factors. This base can then be used in park planning and development.

2. Providing information which can be used in the interpretive aspects of the park. Certainly much information can be used in both of these aims.

In the summer of 1974 research at Bear Island in the Apostles group was initiated toward fulfilling these goals. This study included the following:

1. Identification, distribution and relative abundance of vascular plants. Mapping of the vegetation.

2. Identification, distribution and relative abundance of terrestrial vertebrate animals and correlation with vegetation.

3. Identification of soil types and construction of a soils map.

4. Development of maps depicting soil use limitations with regard to trails, camping areas, and sewage disposal.

THE VEGETATION SURVEY

Figure 1 is a map of Bear Island showing location of sample plots which were placed on a 200 meter grid. On each plot of 20 x 20 meters, all trees over 4 inches DBH were recorded by species and size. Within each of these plots at the northeast corner a 4 x 4 meter plot was placed and all woody vegetation less than 4 inches DBH was recorded by species and number of stems. A plot 1 x 1 meter divided into 1/25 m^2 subplots was used to record herbaceous ground cover. For each species, the number of 1/25 m^2 plots in which it was rooted was recorded thus giving figures ranging from 0 to 25 indicating abundance. Any species of herbaceous plant noticed within the large 20 x 20 meter plot but not in the 1 x 1 meter plot was given a value of 1. Consequently, the importance of rare plants is slightly increased by the figures. This was done to be certain that locations of all rare plants were properly documented, since preservation of rare species is of increasing concern (Larsen 1975).

The vegetation map shown in Fig. 2 has been drawn with the aid of a computer. Using all of the data collected on herbs, shrubs and trees for calculating indices of similarity and dissimilarity, we constructed this map which differs from Fig. 3, a map drawn using only the trees shown by aerial photography. Logging has been carried out at various times up to about 30 years ago over portions of the Island. The trees which have come in during secondary succession shown by Fig. 3 do not reflect the ground cover plants of the previous forest. Thus, Fig. 2, which includes ground cover and shrubs left over from the past generation, may serve as an indicator of what may happen successionally to the trees depicted in Fig. 3.

THE ANIMAL SURVEY

After forest types had been delineated by a short reconnaissance survey, vertebrate animal study areas were laid out. A breeding bird count was accomplished by using the methods of Svensson (1970). Three plots, eight hectares in size, were established in the three major forest types: sugar maple type, white cedar-mixed hardwood type, and white birch-white cedar type. By traversing these areas at 50 meter intervals and recording all types of bird activity, populations and habitat preferences were determined. Table 1 shows results obtained in each of these areas. Only one species, the black throated green warbler, was found everywhere. Other species had definite habitat preferences (Schulz 1976).

Two small rodents, red backed vole and meadow vole are present. Their population densities were measured by placing Sherman live traps in various habitats, marking captured animals by toe clipping and recapturing marked animals. Population densities were calculated using the methods of Schumaker and Eschmeyer (1943). Table 2 illustrates differences in vole populations in various habitats. In general, meadow voles prefer more open vegetation but they occur together in most areas, with red back voles being more numerous.

Red squirrels were sampled by a modification of King's strip census (Leopold 1933). Table 3 shows that these squirrels lived only in areas where cone and catkin bearing trees were found.

One pair of red foxes and a kit roamed over all of the island. Scats were found and several sightings confirmed their presence.

Areas occupied by snowshoe hares and white tailed deer were determined by fecal pellet counts and to some extent by sightings of the animals. Figure 4 shows the range of these animals in the summer of 1974 when it was restricted to the northern area where white cedar and white birch are the dominants. In the summer of 1976, both deer and hares had expanded their numbers and are present in all habitats; in some places they have become quite numerous. This is an example of expansion from most desirable range to the less suitable as numbers increased.

Red backed salamanders and eastern wood frogs are both commonly observed in most habitats. Two other amphibians, the American toad and leopard frog were much less common. One reptile, the garter snake, was rarely found.

SOILS INVESTIGATIONS

Since no soil survey of this island had ever been made, soil pits were dug and auger borings made at appropriate locations over the entire

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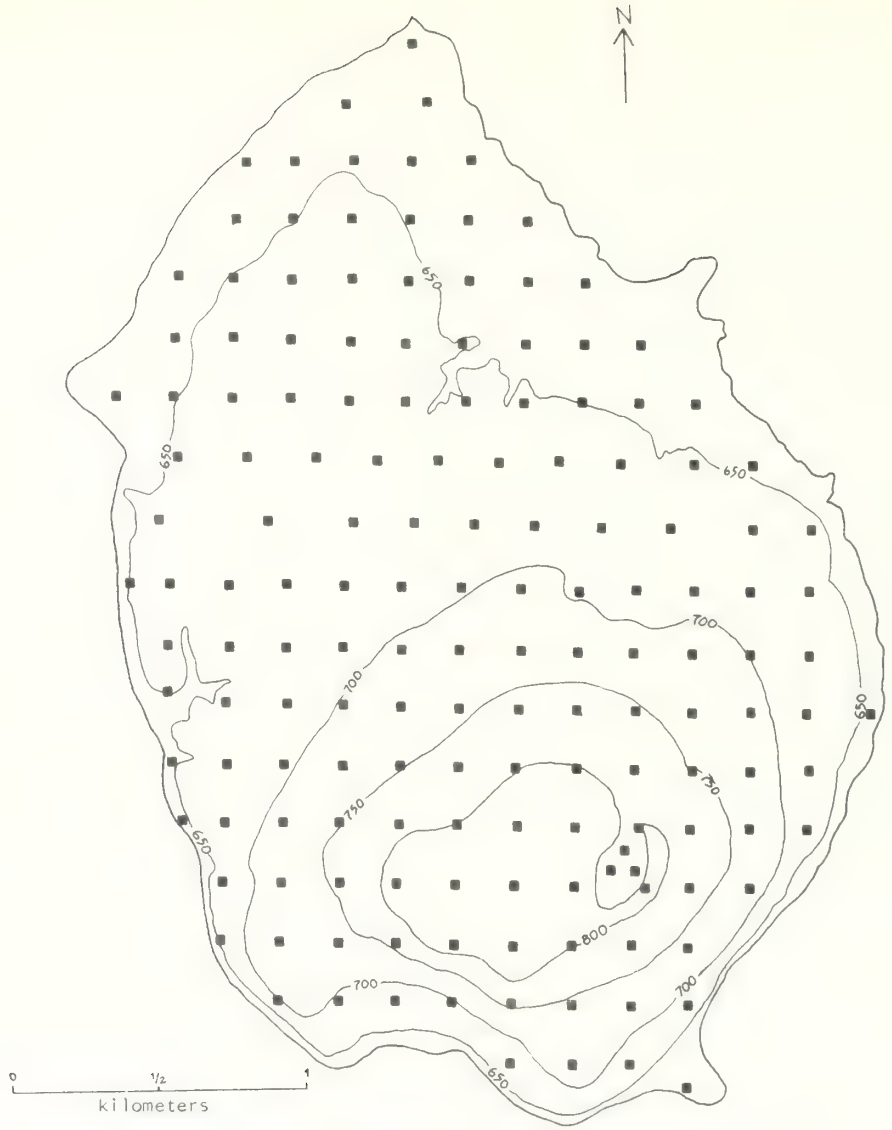

FIGURE 1. Location of vegetation sample plots.

Figure 2
Vegetation Map of Bear Island, Apostle Islands National Lakeshore.

Community Types

I	Pinus strobus-P. resinosa
II	Larix laricina-Pinus strobus-Picea mariana (Bog habitat)
III	Tsuga canadensis-Betula alleghaniensis-Acer saccharum
IV	Thuja occidentalis-Betula papyrifera-Tsuga canadensis
V	Acer saccharum-Betula alleghaniensis-Acer rubrum
VI	Thuja occidentalis-Betula papyrifera-B. alleghaniensis
VII	Thuja occidentalis-Betula papyrifera-Abies balsamea
VIII	Beach area

TABLE 1. Bird species densities in three forest types.

SPECIES	DENSITY PAIRS PER 100 HECTARES		
	SUGAR MAPLE	WHITECEDAR HARDWOODS	WHITEBIRCH WHITECEDAR
Black-throated Green Warbler	38	63	75
Red-eyed Vireo	40	25	--
Ovenbird	40	50	--
Black and White Warbler	25	--	--
Wood Pewee	13	--	--
American Redstart	13	--	25
Robin	13	13	--
Hermit Thrush	--	25	--
Hairy Woodpecker	--	13	--
Nashville Warbler	--	13	--
Blackburian Warbler	--	13	25
Blue Jay	--	--	13
Parula Warbler	--	--	25
Myrtle Warbler	--	--	13
Least Flycatcher	--	--	13
Black-capped chickdee	--	--	13
Red-breasted Nuthatch	--	--	13
Swainson's Thrush	—	—	25
TOTAL	182	215	240

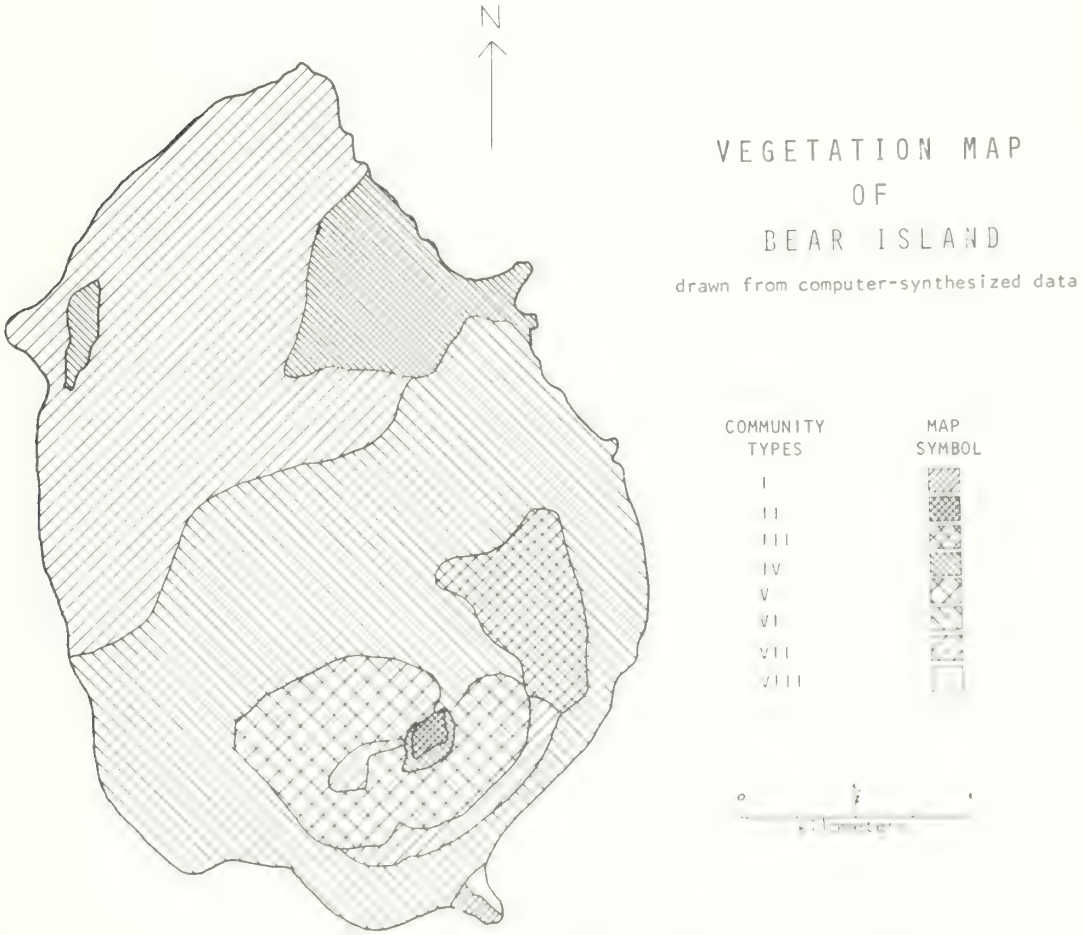

FIGURE 2. Vegetation map of Bear Island, Apostle Islands National Lakeshore.

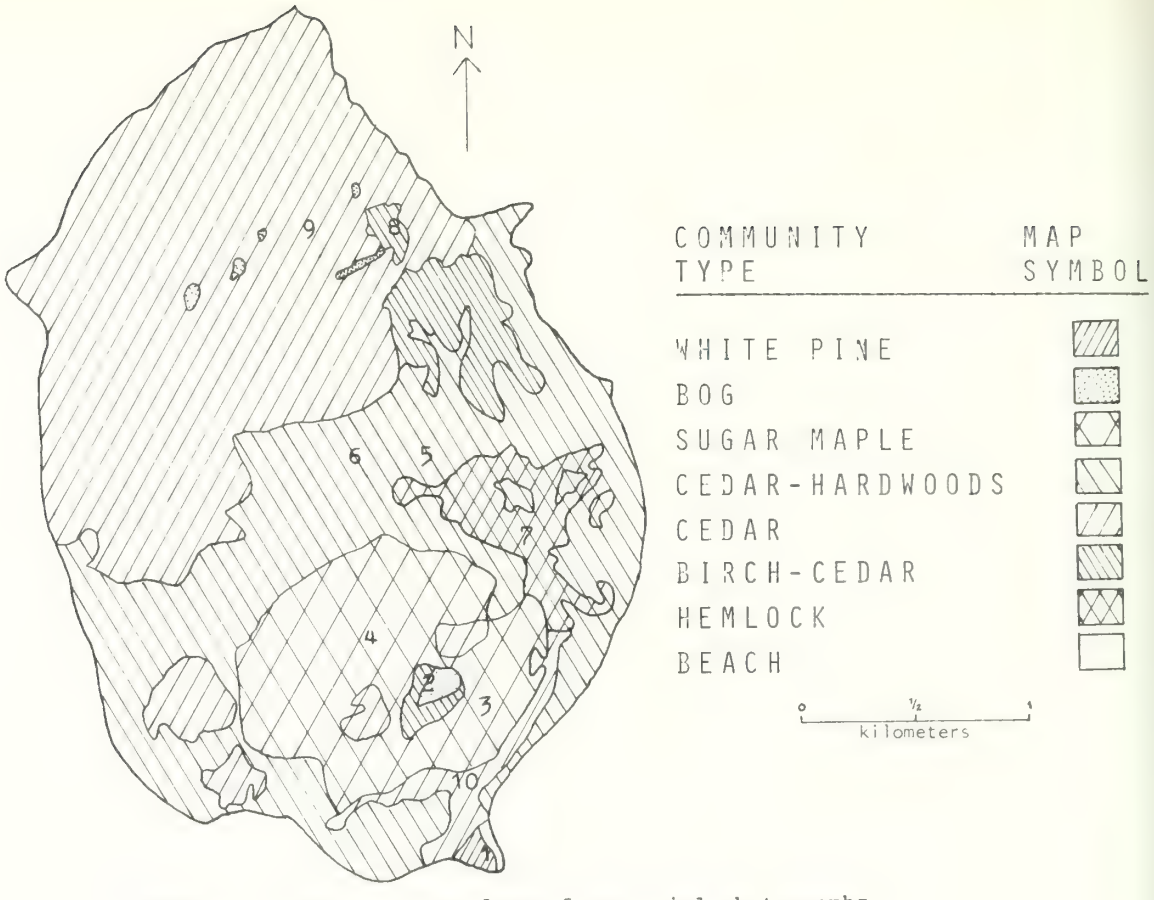

FIGURE 3. Forest type map drawn from aerial photographs.

TABLE 2. Population estimates of voles in various forest types.

PLOT NUMBER	VEGETATION DATE	SAMPLINE DATE	SCHUMAKER & ESCHMEYER POPULATION ESTIMATE	
			RED-BACK VOLE per ha.	MEADOW VOLE per ha.
2	BOG	JUNE 26-JULY 2	---	---
3	SUGAR MAPLE	JULY 28-AUG 3	5.7 (±0.6)	---
4	SUGAR MAPLE	AUG 21-27	1*	6.7 (±1.1)
5	CEDAR-HARDWOODS	JULY 12-18	8.5 (±3.1)	2.9 (±1.4)
6	CEDAR-HARDWOODS	JULY 20-26	1*	16.9 (±2.6)
7	HEMLOCK	AUG 13-19	31.5 (±3.6)	---
8	BIRCH-CEDAR	JULY 4-9	27.5 (±1.4)	4.8 (±2.0)
9	CEDAR	AUG 5-11	8.3 (±2.0)	---

* Actual number of voles caught.

Standard error enclosed by parenthesis.

TABLE 3. Relative abundance of red squirrels in various vegetation types.

VEGETATION TYPE	NUMBER SEEN/1000m	NUMBER HEARD/1000m	TOTAL ENCOUNTERED /1000m	KING'S ESTIMATE #/ha.
Sugar Maple	0	0	0	0
White Cedar Hardwoods	0.4	1.3	1.3	0.6
Hemlock	0.3	2.3	2.4	0.7
White Birch-White Cedar	1.0	2.6	2.6	0.8
White Cedar	1.5	3.9	4.0	1.2

WHITE-TAILED DEER AND SNOWSHOE HARE

SNOWSHOE HARE

NEITHER ANIMAL PRESENT

FIGURE 4. Ranges of white-tailed deer and snowshoe hare.

island. Analysis of samples collected was carried out in the laboratory and a soil map drawn using both field and laboratory data (Kowalski 1976).

After the soil map was constructed, various factors of greater importance in the determination of trails, campsites, and sewage disposal were analyzed and soil limitations maps were prepared.

A complete discussion of the soil aspect of this project is found in the paper by William L. Kowalski in these Proceedings. The soil map and soil limitation for various purposes are also shown.

CONCLUSION

From all these data (flora, fauna, beach lines and soils) a management plan may be developed. Any trails, campsites, docks, or toilet facilities may be planned for the most suitable sites, while areas best adapted for wilderness can now be identified and left undisturbed.

LITERATURE CITED

KOWALSKI, W.L. 1976. Geology, Soils, and Recreational Limitations, Bear Island, Wisconsin. Apostle Islands National Lakeshore. Unpubl. M.S. Thesis. Mich. Tech. Univ., Houghton, MI. 207 pp.

LARSEN, W.C. 1975. Vegetation Ecology of Bear Island, Apostle Islands National Lakeshore. Unpubl. M.S. thesis. Mich. Tech. Univ., Houghton, MI. 91 pp.

LEOPOLD, A.C. 1933. Game Management. Charles Scribner's Sons, New York. 481 pp.

SCHULZ, R.A. 1976. Animal Ecology of Bear Island, Wisconsin. Apostle Islands National Lakeshore. Unpubl. M.S. thesis. Mich. Tech. Univ., Houghton, MI. 48 pp.

SCHUMAKER, F.X. and R.W. ESCHMEYER. 1943. The estimate of fish population in lakes and ponds. Tenn. Acad. Sci. Jour. 18(3):228-249.

SVENSSON, S. 1970. Bird census work and environmental monitoring. Swedish National Science Research Council. Redaktionstjansten Box 23136 S-10435, Sweden. 52 pp.

RESOURCE MONITORING SYSTEM, CHIRICAHUA NATIONAL MONUMENT, ARIZONA

William H. Moir[1] and William M. Lukens[2]

INTRODUCTION

o manage natural resources it is necessary to o what these resources are, how abundant or what ni ion they are in and how they respond to both th l and man-caused treatments. The Organic th the National Park Service specifies that th l resources shall be preserved for the bene- th present and future generations. Preser- th n is no simple task for both natural succes- d and visitor induced succession act to alter s rce conditions from the time the parks were st lished (Stone 1966). Prior to 1974 Chirica- ational Monument had used subjective, visual as to assess the condition and trends of its eg ation and soil resources. This method was un factory because of the relatively low in- en ty of visitor use. The accumulative effect on vegetation, soil, scenic, geologic and other re rces had been relatively minor. Today in- en fied and concentrated visitor use requires on precise quantitative methods of measuring re rce conditions and trends. The former visual ea cannot alert the land manager to deterio- a g conditions soon enough to apply convenient co rative measures. Nor does it provide the ma er with quantitative information on the re- bo e-bearing capacity such that the natural re- or es will not be irreparably damaged for future s.

In 1974 a resource monitoring system was in- tl led at Chiricahua National Monument (Figure 1). Th system consists of a variety of measurements on permanent field plots of existing vegetation an soil conditions in various management zones. Th quantitative data and photographic records cr ated over periods of time will enable manage- ct to:

Objectively evaluate existing conditions of vegetation and soils and their trends in each management zone;

Identify areas of high visitor or maintenance impact, and decide if deleterious or irrevers- ble resource damage is resulting;

Determine when visitor or maintenance regula- ions or controls will be needed to restore deteriorated areas;

Procure baseline measurements from which suc- cession and natural impacts can be compared;

Help in appraising with increased precision the visitor carrying capacity in each manage- ment zone.

This paper describes the resource monitoring system, reviews vegetation types and soil charac- ristics from the perspective of management zones d discusses and summarizes the data procured in 1.

METHODS

The resource monitoring system at Chiracahua tional Monument (CNM) concerns vegetation and soils. More specifically it deals with aspects of plant succession, and the treatise by Daubenmire (1968) is an important reference on theory and techniques. We gave emphasis on reliability and repeatability of measurements and discriminating natural and man-caused succession from vegetation or soil changes caused by making the observations themselves. These latter, "apparent" measures of resource change are brought about by location effects, worker bias, and observational disturbances. The procedures for minimizing these and the statistical theory underlying the monitoring system are given in Moir and Lukens (1975).

The resource monitoring system consists of permanently established plots and photographic locations in various management zones. Three types of plots each use systematically deployed 2 x 5 dm quadrat frames for measuring vegetation by the canopy coverage method (Daubenmire 1959) and soil surface properties (litter, vegetation basal area, exposures of rocks, mineral soil, cryptogams). These plot types are:

1. Belt Transect (BT) Plots. Ten contiguous quadrat frames are arranged into a 2.0 x 0.5 m rectangle. Location effects of each plot were minimized by placing steel rods at corners of one long side of the rectangle. BT plot locations were deliberately selected at microsites of high impact sensitivity; i.e. where vegetation or soil succession could easily be initiated by some kind of disturbance, and where such disturbance was also very probable during the interval between measurements. At such microsites the long axis of the 2.0 x 0.5 m rectangle was oriented in a manner to reveal maximum potential impact.

2. 25-Quadrat Transect (T) Plots. Permanent stakes were placed 25 meters apart within a plant community judged to be rather simple and homogenous (Pielou 1969:203). At a point 0.5 m from one stake and thereafter at 1 m intervals the quadrat frame is placed for vegetation and soil measurements.

3. Forest (F) Plots. This technique works well in oak and pine-oak forests at CNM (see Daubenmire 1968, especially his Figure 26 on p 87). A 25 x 5 m rectangle was staked at each corner. Inside each 25-meter side quadrat frames were arranged as described for T plots and used for measurements of understory herbs and shrubs and soil surface properties. Two additional 25 x 5 m rectangles were added to each side of the original to give a 25 x 15 m macroplot divided into three 5-meter wide strips. All trees in each strip were tallied by size classes. All vascular plants not measured in the 50 quadrats were recorded for constance if occurring within the macroplot.

Succession at CNM was also documented from camera locations (photo-points). We rephotographed whenever possible the earlier photographs of Roseberry and Dole (1939). Stakes, cairns, or painted dots were used to precisely mark the camera tripod location. Data recorded included the direction of camera view and qualitative vegetation description, date and time of day, prominent soil or microsite features, lichen coverage of rocks, and other interpretive items (Mosby 1963, Magill and Twiss 1965). A meter stick or 2 x 5 dm quadrat frame was included in most photographs for scale.

[1]Box 31, Rodeo, New Mexico.

[2]Saguaro National Monument, Tucson, Arizona.

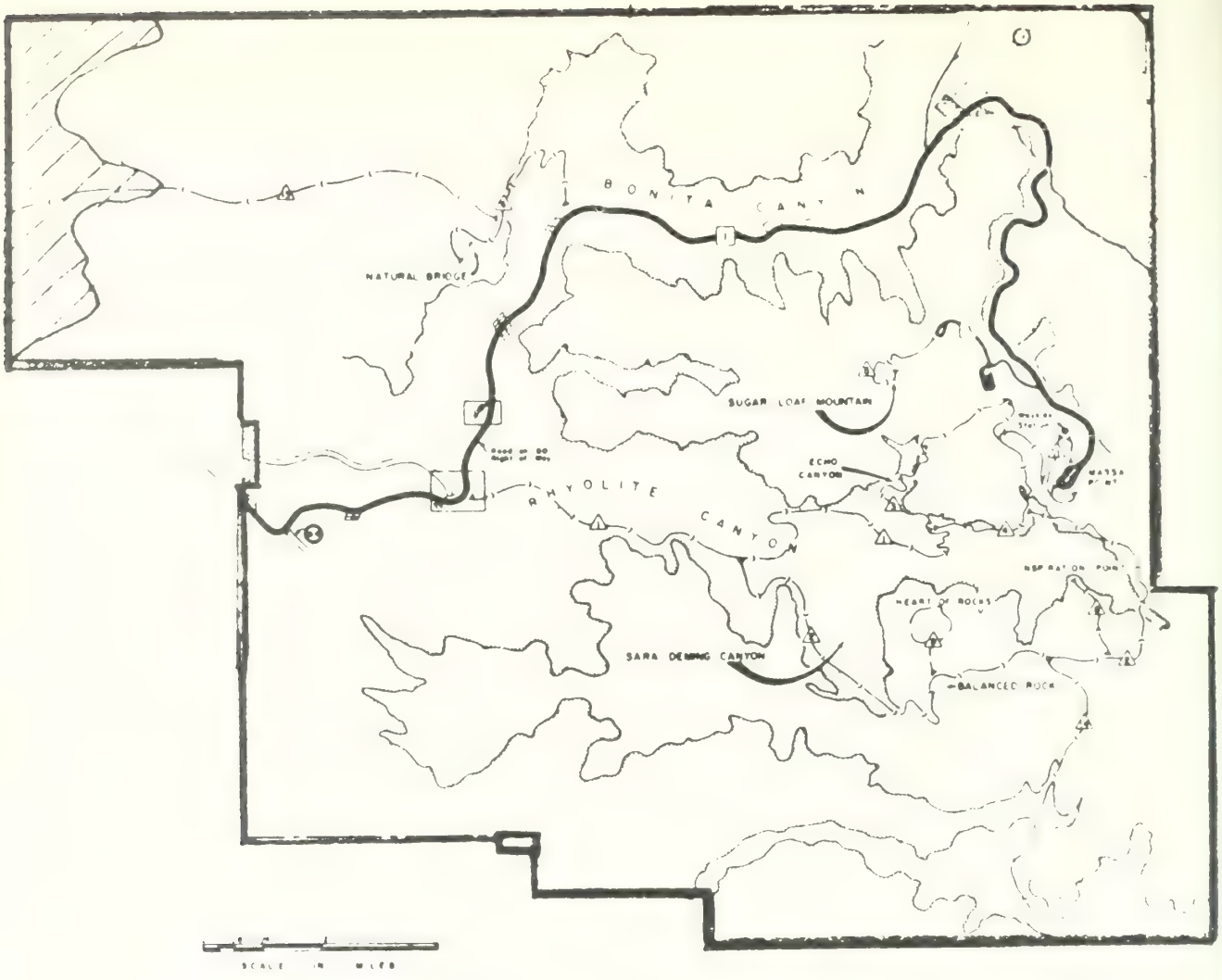

FIGURE 1. Map of Chiricahua National Monument.

DATA SUMMARIES

The overall dimensions of the resource monitoring system established in 1974 are given in Table 1. Field data and analysis is described below.

Belt Transects (BT) Plots

Refer to Tables 2 and 3. Because of the deliberate location of BT plots in areas of high impact sensitivity, data derived from these plots cannot be regarded as descriptions of plant or soil characteristics of the ecosystems where the samples are located. The system of plots is rather a monitoring system intended to reveal impacts at the earliest moment. In examining these tables it is important to keep in mind that they reflect existing vegetation and soil conditions and not the dynamic or trend conditions. The short sampling interval between spring and summer measurements was primarily to determine aspection and not succession. Thus, the occurrence of annuals in the late summer plots is a seasonal feature not necessarily a successional trend. Only year to year measurements in a given season might reveal the latter. Trend, however, can be reasonably deduced during field measurements from overall impressions of vegetation and soil patterns in each sample location and from collateral observations and comparing impacted with non-impacted microsites at each sample location.

Massai Point, Sugarloaf NNE, Massai South

Vegetation and soil surface conditions at Massai Point when compared to the control are Sugarloaf NNE and Massai South, can be summarized and evaluated as follows:

1. Off-trail use by visitors has resulted i apparent deterioration at localized sites, b except for plot 5 such past usage is not reflected in the data.

2. Future, or intensified, unrestricted vis tor activities can be expected to produce th following changes in the BT plots:

   a. Dieback through mechanical breakage woody shrubs and thus reduction of canopy coverage values of Table 4;

   b. Removal of surface litter, soil and gravel materials and resultant increases in the proportions of loose rock and bedrock in Table 5;

   c. Reduced cover of saxicolous *Parmelia* and other lichens as abrasion losses exceed colonization and growth rates.

3. Impact problems related to trail maintenance can be reduced by avoiding borrow area and importing trail materials via the parkin lot, and by judiciously closing off "invitin entranceways to discontinue trails or shortc

TABLE 1. Resource monitoring system, Chiricahua National Monument, 1974.

MANAGEMENT ZONE	LOCATION	PLOT TYPE	NUMBER OF PLOTS
Road Corridor	Massai	BT	7
	Bonita-Faraway	BT	12
Environmental Study Area	Silver Spur	BT	8
Trail Corridor	Rhyolite Canyon	BT	8
		F	2
	Natural Bridge	BT	8
	Heart of Rocks & Echo Canyon	BT	11
Natural Areas	Picket Park	F	2
	East Picket Park	T	2
	Jesse James	F	1
		T	2
Wilderness	Sugarload NNE	BT	6
	Massai South	BT	10
	SW Corner	T	3
	Picket Canyon	T	1
		T	1
	Whitetail Canyon	T	2
	Bonita Canyon	F	1
Campground	Perimeter	BT	13
	Perimeter	BT	11

areas through site management with native plant species.

Heart of Rocks and Echo Canyon Trails

Trail maintenance and visitor off-trail use seem to present similar problems to Massai Point. These problems are only serious along the start of these trails. Where the trails intersect in upper Rhyolite Canyon and continue down the canyon, the plots reveal little or no signs of man-caused disturbance. Applications similar to those suggested for Massai Point may be applied.

Bonita-Faraway Hills

Bonita-Faraway is important despite its location along the road corridor as a non-used control area. There is little or no evidence of any deleterious wildlife or visitor impact in or near any of the 12 plots.

Campground

An initial reconnaissance of this zone suggested three main types of visitor impact in the perimeter area: trampling, wood gathering and trash dispersion. Findings were:

1. A number of entry points into the campground perimeter from the main campground were obvious.

2. Once into the perimeter area, trails branch, network, and anastomose along numerous corridors.

3. People walk as much as possible through open grassy areas in marked preference to crashing through shrubby barriers.

4. The HI zone intergrades imperceptibly into the IO zone as terrain gets steeper, but there appears to be no non-use zone within 200 meters of the campground margin.

Based on these findings plots were established in both HI and IO used zones. Evaluation of the data collected from these plots suggests the following:

1. Although resource deterioration has commenced, especially in the immediate campground perimeter, it has not progressed to alarm proportions.

2. Active management of camper activities to lessen their uncontrolled effects upon

TABLE 2. Canopy coverage (C) in BT plots, spring 1974, and number of plots where cover increased (+), remained constant (o), or decreased (-) between spring and summer. Coverage has been averaged to the nearest percent over the number of plots where the taxa occurred at each location. Canopy coverage for the annual species are summer observations only.

	MASSAI		MASSAI SOUTH		SUGARLOAF NNE		RHYOLITE CANYON		NATURAL BRIDGE		HEART OF ROCKS & ECHO CANY.		BONITA-FARAWAY		CAMPGROUND HI		CAMPGROUND LO	
TAXA	C	+ o -	C	+ o -	C	+ o -	C	+ o -	C	+ o -	C	+ o -	C	+ o -	C	+ o -	C	+ o -
ARPU	39	3 2	14	2 5 1	31	3	18	1 1	10	1 1	30	3 1	22	3 3	21	1 7 1	11	2 2
QUTO	12	1	22	2	24	1 2			19	4	17	1 4			16	1	22	1 4
QUHY	18	1 1	4	2	22	1 2	1	2	29	3 1	26	2 1						
QUEM													16	1	16	2		
QUAR							1	1 3	44	3			99	1	40	3		
QURE			17	1 1							40	1 1						
GAWR									22	2	4	1						
RHCO							8	1	0	1					0	1		
RHTR							9	2										
NOMI			0	1	15	1	9	3			20	1			11	3		
AGPA					1	1			0	1	0	1	0	1 1	0	1 1		
Catclaw							2	2 1 1					4	1	14	3 2	11	1 1
JUDE							2	1	99	1	23	1	30	1	12	2		
CUAR	55	2	20	1 1	28	1			39	1	99	1	99	1				
PICE	22	4	42	4					14	2 2 1	37	3						
PILE							2				29	1						
Other					0	2	2	4 1	0	3	0	4	0	6 1	11	5	1	5
Annuals	28	3	27	7	26	6	1	3	4	7	11	6	62	12	13	13	17	10
Graminoids	0	1	1	1 1	4	2 2	20	6 2	28	5	2	2	31	2 7 3	30	4 7 2	21	2 5 4
Parmelia	9	2 2 1	5	8 1	5	2 4	1	2	1	1 4	3	2 6 1	2	1 9 1	0	4	0	5
Lichens	4		1	1 8 1	1	3 1	0	2	1	4 1	1	6 2	1		0	3 2	1	4 3 1
Soil Crypto.		3		1 6		3 1		2 1		2 2 1		5 1		4 3 3		4 1		1 1 2
No. Plots	7(7)		10(10)		5(6)		8(8)		9(8)		11(11)		12(12)		13(13)		11(11)	
Trash	1(1)		0(0)		0(0)		0(1)		0(0)		4(2)		0(0)		3(3)		0(0)	

TABLE 3. Soil surface characteristics at belt transect plots, Chiricahua National Monument, 1974.

DESCRIPTION	LOCATIONS								
	MASSAI	MASSAI SOUTH	SUGARLOAF NNE	RHYOLITE CANYON	NATURAL BRIDGE	HEART OF ROCKS & ECHO CANY.	BONITA-FARAWAY	CAMPGROUND HI	CAMPGROUND LO
No. Plots a/	7	10	5-6	8	9-8	11	12	13	11
SOIL & GRAVEL b/									
Spring	45(13-86)	42(7-92)	58(33-90)	2(a-7)	9(2-31)	29(1-58)	52(5-78)	46(5-89)	61(29-94)
Summer	39(9-85)	43(4-87)	61(30-87)	2(a-6)	10(2-33)	32(1-54)	55(2-74)	48(2-82)	66(39-86)
LOOSE ROCK									
Spring	9(1-20)	2(a- 7)	6(1-18)	0(a-2)	3(a-19)	6(0-16)	7(1-12)	5(a-14)	11(1-18)
Summer	6(a-14)	1(a- 4)	4(0-15)	0(a-3)	4(a-17)	4(a-12)	7(2-11)	4(a-12)	8(a-19)
BEDROCK									
Spring	12(a-59)	3(a-15)	8(a-15)	0(a-3)	4(a- 9)	5(a-22)	4(a-22)	5(a-18)	4(a-17)
Summer	20(a-78)	4(a-15)	7(a-18)	0(a-2)	4(a-11)	8(a-34)	5(a-21)	7(a-22)	5(a-15)
LITTER									
Spring	34(3-66)	52(8-91)	27(0-64)	94(32-99)	83(60-95)	60(24-96)	28(4-87)	39(3-76)	20(3-52)
Summer	34(2-67)	51(13-91)	26(2-68)	96(94-99)	81(50-98)	55(25-77)	31(13-89)	38(6-81)	19(4-42)
VEG. BA									
Spring	a	0(a- 0)	0(a- 2)	2(0- 5)	1(a- 5)	1(a- 1)	9(2-21)	5(0- 8)	4(1- 6)
Summer	0(a- 0)	0(a- 0)	1(a- 2)	2(a- 4)	2(0- 6)	0(a- 4)	3(1- 6)	3(0- 7)	2(0- 5)
TOTAL c/									
Spring	100	99	99	98	100	101	100	100	100
Summer	99	99	99	99	99	99	101	100	100

a/ Number of plots during both spring and summer measurements, if different. b/ Numbers rounded to nearest percent, range of percentages in parentheses, a = absent; c/ rounding errors may cause deviation from 100.

TABLE 4. Forest size and taxonomic structure at F plots in canyons of Chiricagua National Monument, spring 1974. Plots F1 and F2 occur in Picket Park, F3 and F4 Rhyolite Canyon, F5 Jesse James Canyon, and F6 Bonita Canyon. The five size classes are respectively 0-1, 1-2, 2-3, 3-4, and 4-5 dm Dbh (diameter at breast height). The + in the body of the table indicates presence outside the 25 X 15 m plot.

CANOPY LAYER AND TAXA	PLOT AND SIZE CLASS																															
	F1					F2					F3					F4					F5					F6							
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5		
Tall Conifers	----------stems/375 m^2----------																															
Cupressus arizonica											4	+			+	+										1						
Pinus leiophylla	1	3	1	2		3	2	3	1		3			1			+		+	1						3	+			+		
Pinus engelmanni						2			2	2	5	1					+			+	+											
Evergreen Oak Layer																																
Pinus cembroides	3					6					7					7					5					2						
Juniperus deppeana		6	1	2		15			1	2						1					4					62	8	1	1			
Quercus hypoleucoides	1										2	12	2	1		7	22				4	26	4									
Quercus arizonica											1	25	5	1		4	21	2	1		4	16	2			1	4					
Quercus emoryi	1	2					2	3	1			2							1			3				2	13	6	4			
Arbutus arizonica													1							+						+						
	----------stems/ha----------																															
Total stem density[a]	479					506					1360					1280					1360					980						

a/ Size classes 2-5 inclusive; young reproduction (size class 1) not included.

vegetation and soils at this stage.

3. Continued, sustained, and uncontrolled visitor use of the perimeter may "trigger" these slopes whereby precipitation runoff from an intense storm may produce great resource and campground damage.

4. The campground perimeter shows generalized rather than localized camper impacts as evinced by numerous meandering pathways, crushed vegetation, scattered trash, vandalized monitoring plots, and chopped woody branches and limbs.

Forest (F) Plots (Tables 4,5)

These plots, unlike the BT plots, are descriptive samples of plant and soil characteristic of the forest stands. Although the location of each macroplot is conditioned by somewhat subjective appraisal of vegetation homogeneity and buffering against edge effects, there was no attempt to locate the frames only in sensitive area. Descriptions provided by these F plots are useful as baselines or benchmark measurements against which future changes such as fire can be compared (Moir 1973).

Those management zones in which F plots were established (Rhyolite Canyon, Picket Park, Jesse James, Bonita Canyon) generally reflect little visitor impact. The mantle of woodland litter is good, the cover of grasses respectable and there is a rather high wildflower species diversity. Where Research Natural Areas are involved care must be taken to insure that all use including resource monitoring is controlled.

25-Quadrat Transect (T) Plots (Table 6)

At selected locations (East Picket Park, Jesse James, SW corner Picket Canyon, Whitetail Canyon) where description of the herbaceous ground flora was of special interest, the monitoring system consisted of T plots. Table 6 summarizes the data. In this table the first group of taxa are perennial grasses from the late summer observations (at this season identification is most certain, and folias measurements are often at the year's maximum after summer rains). The second group of taxa include some of the summer annuals, an important lifeform in these savanna or grassy habitats. Soil surface features, the final group are spring measurements for plots T10 and T11 and summer measurements for the remaining plots.

Picket Canyon

Plots T1 and T2 were located where trespass grazing had occurred. The coverage and basal area of these palatable grasses suggest that cattle grazing has been of slight, if any consequence. Gully erosion had taken place on some slopes, but older gullies exhibited vegetation and stabilization. Grazing and cattle bedding may have reduced canopy coverage during the spring measurement period, but basal area was very high and no overgrazing could be concluded. Any depauperization of palatable herbaceous species by past cattle grazing in this area was undetectable.

Whitetail Canyon

Portions of this canyon received greater grazing impacts than Picket Canyon and exhibit considerably lower canopy coverages. Recent, unhealed gullying was conspicuous on red lakebed soils of plot T3. The recent grazing influence in Whitetail Canyon is only of sporadic local severity.

Jesse James

Livestock grazing continues to be a factor of vegetation expression. Basal area of the perennial grasses is good, suggesting that livestock management here has not reduced the capacity of the graze tolerant blue grama for forage production. There are no signs of soil erosion. Plot T9 located in the adjoining pasture and being grazed in 1974 by horses, had similar vegetation composition, although certain annual species seemed of greater dominance than in plots T7 and T8 across the fence.

East Picket Park

The plots in this natural area are in somewhat similar microhabitats to many of the BT plots of the campground perimeter. In addition these plots are well off and beyond sight of

TABLE 5. Understory vegetation and soil surface characteristics in forest plots Chiricahua National Monument, 1974. The + indicates constance.

	TAXA	COVER(%)/FREQUENCY(%) BY PLOT					
		F1	F2	F3	F4	F5	F6
SHRUBS	Arctostaphylos pungens	13/22	+				9/22
	Garrya wrightii	+	+		0/ 2	+	0/ 4
	Rhus coriophylla				+	2/2	
	Nolina microcarpa		+	6/16	2/14	1/4	
	Yucca schottii	0/ 2	1/ 4		0/ 4	+	
	Dasylirion wheeleri			1/ 2			
	Agave palmeri						
	Quercus hypoleucoides		+	4/10	15/34	7/14	
	Q. arizonica			2/ 4	2/ 6	3/ 8	
	Q. emoryi	4/ 6					2/ 6
	Rhamnus			3/ 4	1/ 2		
	Rhus trilobata		1/ 4			+	2/10
	Bouvardia glaberrima			+			
	Toxicodendron radicans			0/ 4	+		
	Lonicera albiflora		+				
GRAMINOID PLANTS	Muhlenbergia sp.	9/38					
	M. longiligula	2/ 4	44/80	1/ 6	8/24	6/22	5/14
	M. emersleyi	0/ 2	+	1/14	2/ 8		
	Andropogon cirratus	0/ 4		+			
	Aristida orcuttiana	14/68	0/ 2	1/14			1/ 2
	A. longiseta	1/ 2					
	Panicum bulbosum		0/ 2	+			
	Piptochaetium fimbriatum	+		+			8/24
	Carex sp.		1/ 8	0/ 2			0/ 2
FORBS	Clitoria mariana						12/74
	Oxybaphus	0/ 6	+				1/18
	Brickellia lemmonii						
	Brickellia	+	0/ 4				
	Polygala obscura	0/ 4		0/ 2			
	Phaseolus heterophyllus	1/10					
	Other perennial herbs		0/12	+			0/ 6
ANNUALS	Drymeria sperguloides	15/64	1/ 6				
	Muhlenbergia	6/20					
	Cyperus aristatus	3/52	0/ 4				
	Schistophragma intermedia	1/24	0/ 2				
	Bulbostylis funkii	11/62					
	Cyperus rusbyi	0/14	1/16				0/ 6
	Acalypha neomexicana	0/ 6					0/ 8
	Other annuals	0/ 2					1/30
SOIL SURFACE	Litter *	84(82)	95(95)	92(91)	89(89)	87	86(88)
	Soil	12(15)	0(1)	0(0)	0	0	14(11)
	Rocks			8(8)	10(10)	12	0(0)
	Vegetation Basal Area	5(3)	5(4)	1(1)	1(1)	0	0(0)
	Soil cryptogams **	2(8)	-(6)		-(4)	2	4(4)

* Average cover only; spring and summer (in parentheses) measurements.
** Average frequency only.

the Natural Bridge Trail and little frequented by visitors or staff. Therefore the data and plant responses between measurement intervals can be useful as baseline measurements or controls for similar habitat (which is widespread in the monument) in which visitor impacts might initiate succession.

Environmental Study Area

This area reflects not only past historic use (a truck farm in the late 1800's and early 1900's, a CCC Camp in the 30's and a Guest Ranch in the 40's and 50's), but as a study area for school groups reflects present use. As a study area it can be manipulated and various testing methods applied. A trampling experiment with controlled numbers of people was begun as a part of the monitoring system. Results of a three month study indicated that trampling had no effect on basal area cover of pinyon ricegrass or three awn-sideoats grama. However, canopy coverage showed a greater increase in the control area than in the trampled area. In general it was concluded that the grasses of the oak woodland forest floor have a remarkable durability to man's off-trail trampling, but that it should not be concluded that microsites other than woodland floors would be as resistant. It does, however, indicate the usefulness of such an area for experimentation as well as the value of the monitoring system in providing baseline data.

A summary of the data evaluation for the ESA is as follows:

1. A variety of habitats exist ranging from highly fragile (the spring-seepage area) to relatively durable and resilient (oak woodlands) to visitor use.

TABLE 6(a). Major herbaceous and soil surface characteristics at T plots, Chiricahua National Monument.

TAXA	COVER (%)/FREQUENCY (%) BY PLOT [a]					
	T1	T2	T3	T4	T5	T6
Andropogon barbinodis	+	5/20				
A. cirratus				0/ 4	14/76	13/48
Aristida orcuttiana		0/ 8			5/28	1/12
A. longiseta			0/ 4			
Bouteloua curtipendula	0/ 8	6/32	+	4/40	5/48	10/52
B. eriopoda		2/16				
B. gracilis	5/24	13/52	1/ 4			
B. hirsuta	10/60	1/ 4		2/40	4/56	5/80
Elyonuras barbiculmis						8/32
Eragrostis intermedia		4/20			+	0/ 4
Hilaria belangeri	30/100					
Lycurus phleoides	+	+		1/ 8	1/ 8	3/12
Muhlenbergia emersleyi		+		1/ 4	14/36	13/20
M. longiligula		1/ 4				
M. wrightii			1/12			
Panicum bulbosum		1/24				
Piptochaetium fimbriatum		21/32	15/44		0/ 4	
Koeleria cristata			5/40			
Acalypha neomexicana		2/36	0/20		1/12	
Aristida adscensionis				0/ 8		
Bulbostylis funkii				2/24	7/28	0/ 4
Crotalaria pumila		2/24	0/ 4	5/60		
Cyperus aristatus			0/12			
Dalea filiformis	+		0/20	+		
Desmodium procumbens		7/44		5/24	+	
D. rosei		5/48	12/72			
Drymeria sperguloides	1/52	1/12		4/52	9/28	5/40
Eragrostis	0/ 4	1/12	0/12	2/12		0/ 4
Euphorbia sp.	1/20		1/36	4/40		
E. revoluta	4/68	2/44		3/56		
Ipomaea costellata	2/32	0/ 8				
Kallstromia parviflora						
Muhlenbergia sinuosa			4/60	14/96	+	+
Pectis filipes			1/ 8	7/56		
Portulaca mundula	2/60	3/36	0/ 8	1/28		
Salvia subineisa						
Schkuhria wislizeni					+	
Schistophragma				0/20	1/12	0/ 4
Setaria grisbachi		+				
Sonchus					1/ 4	
Perennial herbs	1/ 4	2/16	10/88	3/40	10/40	2/36
Vegetation BA [a]	9	7	2	1	4	4
Litter	8	71	63	22	56	40
Soil & Gravel	75	22	35	78	39	44
Loose Rocks	8		0	0	1	12
Bedrock			0			
Soil Cryptogams		4		12	4	

[a] Average cover only for soil surface features; frequency for soil cryptogams.

2. Man's activities here prior to the establishment of the Monument have severely impacted much of the area, but much of the area also exhibits at least some degree of natural vegetation composition.

3. Utilization of the area for visitor group activities must be determined on bases of the size of the group, their planned activities, the duration of their visit, their behavior, which habitats are to be visited, and the proximity of fragile and durable habitats.

4. If deleterious effects upon the habitats within ESA by visiting groups are noted, these habitats should be allowed a "rest and recovery" period by redirecting group activities to alternative areas such as the Stafford Cabin.

5. Plant collecting activities around the spring-seepage area should be prohibited.

6. Vegetative restoration efforts along old roadways and other denuded sites should be attempted.

7. Interpretative displays in degraded areas can emphasize to the visiting public some of the more heavy-handed and permanent consequences of man's dominance within some of the Monument's typical ecosystems. Displays involving ecological costs and environmental consequences of accommodating the visitor in the Monument can also be made. Should these costs be hidden? Or should the interpretative program of the Monument be extended to include man in the ecosystem? The opportunity is there.

RESOURCE EVALUATION

Data from monitored locations and photographic sites permit assessment of vegetative and soil conditions at Chiricahua National Monument as stated by the objectives in the Introduction. A tabularized summary of this evaluation is given in Table 7.

TABLE 6(b). Major herbaceous and soil surface characteristics at T plots, Chiricahua National Monument.

TAXA	COVER (%)/FREQUENCY (%) BY PLOT [a] T7	T8	T9	T10	T11
Andropogon barbinodis					
A. cirratus				3/36	1/16
Aristida orcuttiana				7/32	1/ 4
A. longiseta					
Bouteloua curtipendula				0/ 4	0/ 4
B. eriopoda					
B. gracilis	45/100	32/100	34/100		
B. hirsuta		0/ 4			
Elyonuras barbiculmis					
Eragrostis intermedia				+	
Hilaria belangeri					
Lycurus phleoides	+		1/ 4	0/ 4	+
Muhlenbergia emersleyi				3/24	11/28
M. longiligula					
M. wrightii					
Panicum bulbosum					
Piptochaetium fimbriatum				+	
Koeleria cristata					
Acalypha neomexicana					
Aristida adscensionis	37/100	4/68	1/36		
Bulbostylis funkii				29/72	11/52
Crotalaria pumila					
Cyperus aristatus				3/44	1/44
Dalea filiformis					
Desmodium procumbens					
D. rosei				0/16	1/ 8
Drymeria sperguloides	2/40	0/16	6/76	10/64	4/44
Eragrostis	0/ 4		0/20		
Euphorbia sp.					
E. revoluta			2/16		
Ipomaea costellata					
Kallstromia parviflora	1/20	0/ 4	34/80		
Muhlenbergia sinuosa				1/24	2/12
Pectis filipes				19/88	13/68
Portulaca mundula	14/92	0/16	10/92		
Salvia subineisa	0/16	+	0/ 8		
Schkuhria wislizeni		1/12	0/ 8		
Schistophragma				1/20	2/32
Setaria grisbachi					
Sonchus					
Perennial herbs	1/ 4	2/32	3/24	1/12	0/ 8
Vegetation BA [a]	10	4	5	2	1
Litter	16	8	14	36	25
Soil & Gravel	74	88	81	48	44
Loose Rocks				6	9
Bedrock				8	20
Soil Cryptogams					

[a] Average cover only for soil surface features; frequency for soil cryptogams.

Generally the resources examined at Chiracahua National Monument in 1974 appeared in excellent condition even at locations that maintained heavy visitor traffic in past years. Such generalization is supported by photography of Roseberry and Dole in 1937, and other earlier Monument photographs. These photos generally revealed a vegetation little different from that of today, after many thousands of visitors. With certain exceptions at local areas such as the spring at ESA the vegetation of the Monument appears hardy and durable, with slow rates of change in the absence of fire, and probably in climax or near-climax conditions over many areas. So long as vegetative cover remains high, soil stability will remain good in the canyon bottoms and lower canyon slopes. Upper canyon slopes and upland rhyolite plateau surfaces generally have rough, broken lands, rock outcrop and bare rock lands, and shallow or skeletal lithosols or excessive runoff. But even here vegetative cover is often very good, as evidenced by the monitoring system, recent aerial photography (USGS 1973), and ground photography of past workers (Roseberry and Dole 1939). In general these upland expressions of vegetation, soils, and geology appear the natural, normal consequences of erosion-sedimentation processes little affected by man's presence in the Monument.

Floristic diversity within the Monument continues to be high. Plant specimens collected in 1939 and 1940 by Ora M. Clark are still well represented by populations apparently maintaining themselves within the various ecosystems. Maintenance of interesting local populations such as *Berberis wilcoxii* and *Pachistima myrsinites* (possibly relicts of postglacial pluvial climates) under present management prescriptions seems assured. In particular, the identification of five natural area locations within the Monument (Arizona Academy of Science and Smith 1974) serves, in part, an important genetic pool purpose (Moir 1972; Franklin et al. 1972). In addition perceptual diversity appears quite high in most areas used by the Monument visitor. Although flower picking along certain heavily used

TABLE 7. Summary of natural resource conditions (vegetation and soils) and estimates of visitor carrying capacity at locations within Chiricahua National Monument, 1974.

LOCATION	CONDITION	CAUSES OF IMPACT	EXTENT	RESTORATIVE MEASURES	CARRYING CAPACITY (x present visitor use intensities)
Massai Point	Good	Off-trail use	Local	Site Management	x 1.5
Bonita-Faraway Hills	Excellent				x 3
Environmental Study Area	Poor	Pre-Monument Activities	General		x 1 - a x 2 - b
Rhyolite Canyon Trail	Excellent	Off-trail use, Flower picking	Local	Site Management	x 2
Natural Bridge Trail	Excellent	Off-trail use	v. local		x 3
Heart of Rocks & Echo Canyon Trails	Fair	Off-trail use, Trash	Local	Site Management, Guided groups	x 1
Natural Areas (Picket Park, E. Picket Park, Jesse James)	Excellent				x 3
Sugarloaf NNE	Excellent				x 1
Massai South	Excellent				x 0.8
Picket, Whitetail Canyons	Excellent	Livestock grazing	Local	Fencing	x 3
Campground	Fair	Trampling, trash, wood-gathering	General	Build trail	x 1 - c x 0.8 - d
Wilderness	Excellent				x 3

a - spring area b - woodlands c - perimeter d - distal perimeter

trail segments may have produced certain floristic impoverishment, evidence for this cannot be produced. Certain cactaceae may have been removed from certain locales, but backcountry locations and even the Road Corridor (at Bonita-Faraway Hills) seem to be supporting good populations. The abundance of other attractive wildlower species at many locations of this resource monitoring system, guarantees at the very least seed sources for possible reintroductions at locally impoverished sites.

Resource deterioration, where occurring under visitor use, is usually confined to local sites as summarized in Table 1. Locations given other than excellent rating revealed localized sites of vegetation or soil wear. For example most of Heart of Rocks or Echo Canyon Trails exhibit stable, diverse, undisturbed vegetation along most of the trail corridor, but have sufficient signs of off-trail use and trash along the initial kilometers to give only fair rating. Only the campground perimeter shows a more generalized visitor use, but even this is not so severe as of 1974 to warrant a poor resource rating. Portions of the ESA location along lower Bonita Canyon also have generalized deterioration, but the poor rating is reflection of slow successional rates of recovery since the resource damage was done in pre-Monument years.

The last column of Table 7 is a second approximation (previously done in 1973) to visitor carrying capacity. Here the objective is to increase levels of visitor use in the management zones without reduction of the resource condition. Certain assumptions governed the carrying capacity estimates of the last column (Wagar 1974; Lime and Stankey 1971; USDA Forest Service 1974). These are:

1. Future management prescriptions do not markedly differ from existing ones. New policies of visitor regulation or control, intensified site management, or other changes could *increase* use intensities in most management zones.

2. Only the consequences upon natural resources were considered. People-to-people interactions might serve to *reduce* the estimated carrying capacities, especially in backcountry areas.

3. Maintenance of the resource status quo was the key determinant. Should undesirable succession trends be observed, then the carrying capacity estimates must be lowered. Similar reductions must be contemplated if restorative or resource improvement efforts are desired management objectives.

4. Visitor attitudes toward the natural resources remain much as they are now. As attitudes, behaviors, and perceptions change then the estimates of the last column must be revised. These changes may result from new directions in environmental education or emergence of new social norms.

Under these assumptions, inferences based upon resource condition existing at the monitored sites suggest that most of the Monument is operating at or below the visitor carrying capacity. Only the campground, Heart of Rocks and Echo Canyon Trails, Environmental Study Area, and Sugarloaf NNE seem to be operating at or near the visitor limits. Most other locations could doubtless sustain greater visitor numbers. Only Massai South, a sensitive and critical control location, might be treated more circumspectly with less visitor or maintenance travel. Here steep slopes and concealed locations of BT plots just off the ridge make them susceptible to unintentioned disturbance, thus losing their validity as controls. Similarly the spring area at ESA might benefit from some visitor reduction, but monitoring at this location is presently inadequate to sufficiently document this quantitatively.

MAINTAINING, REVIEWING AND UPDATING THE MONITORING SYSTEM

To be of continuing value to management the resource monitoring system at Chiricahua National Monument must be reveiwed, revised, and maintained. Some locations are not being monitored at present and should be (e.g. the spring at ESA); other areas need further sampling. Management needs and use patterns of the resources may change. New programs, such as intensified scientific research, may be undertaken in future years. Some monitoring sites may become vandalized or lost, while others could be better relocated. During the 4 month interval between revisiting the monitoring plots in spring and late summer, the attrition rate of monitoring plots (mainly lost or vandalized) could be estimated. At heavy visitor use areas 10 out of a total of 67 BT plots were lost or vandalized in that interval. At that rate the annual attrition is a whopping 45%! Of course many of these plots can be repaired (this usually involves reinstallation of one of the corner stakes), without loss of information. But this high rate (attrition in backcountry locations was 0%) emphasizes the need for maintenance. All plots will require future reobservations of their vegetation and soil conditions. Better sampling techniques may become available. Fortunately the dimensions of the resource monitoring system are flexible. The system can be continually adjusted and tailored to changing needs and conditions at Chiricahua National Monument.

The immediate concern is to continue monitoring the natural resources as part of the Monument's in-house operations. New staff must be trained in the location of field microsites, photographic locations, and the necessary field procedures. A continuous chain of qualified personnel must be assured for future measurements that have high reliability, as discussed under statistical considerations. Cognizance and familiarity with vegetation and soil resources to be measured is an absolute must. Voucher specimens must be examined and reviewed from time to time for familiarity with flora within the numerous plots. If omissions, inaccuracies, and mistakes enter into the data, then the objectives of the resource monitoring system can hardly be met, and more damage than benefit will result.

Observations from the monitoring can be more directly geared to measurements of visitor numbers and activities in different management zones for correlations and more precise estimates of carrying capacities and successional causes. The problem of determining trends will arise as plots are revisited and remeasured. Data analyses follow data collection. Whether comparisons are based upon statistical or nonstatistical procedures, there must nevertheless be data summaries that form the bases for decision making. Statistical work can be farmed out, if necessary. But the system of data collection and summarizing must not be so complicated that valid judgements cannot be made by simple and straightforward examinations of plot data, if need be. Data obtained from control locations are especially useful for these judgements, as are collateral observations at monitoring sites. A system of storing and retrieving field data sheets, assuring against loss, and providing records of continuity for each plot must also be established as the in-house operation. The resource monitoring system can readily form the data basis for evaluating natural resource condition and evaluation during important changes of staff, as for example the periodic turnover of the Monument's Superintendent. Indeed, resource evaluations, in view of the National Park Service's resource preservation mandate, ought to be at least as important as inventories of facilities and equipment! The monitoring system, then, provides an objective, continuing basis of resource measurement and evaluation from one administration to the next.

Plot locations should be revisited and remeasured as often as management deems warranted for issuing regulations, controls, or restorativ measures. The natural resources at some locatic will change very slowly and at other locations quite rapidly as visitor use intensifies or natu al events take place. However, no location shou be frequented too often, because accumulated obs vational disturbances may then exceed or mask possible real effects. Just how often any location should be remeasured is a matter of management's needs and good judgment, as well as available staff time and funding.

LITERATURE CITED

ARIZONA ACADEMY OF SCIENCES and E. L. SMITH. 19 Established natural areas in Arizona, A guid book for scientists and educators. Planning Div., Office of Economic Planning and Develo ment, State of Arizona, i, 300 p.

BRUNK, H. D. 1960. An introduction to mathematical statistics. Ginn & Co., New York, x 403 p.

DARROW, R. A. 1944. Arizona range resources a their utilization. I. Cochise County. Ariz. Agri. Exp. Sta. Tech. Bul. 103:311-366.

DAUBENMIRE, R. F. 1968. Plant Communities: A textbook of plant synecology. Harper and Ro New York, 300 p.

_____. 1966. Vegetation: Identification typal communities. Science 151:291-298.

_____. 1959. A canopy-coverage method of vegetation analysis. Northw. Sci. 33:43-64.

GILE, L. H. and J. W. HAWLEY. 1966. Periodic sedimentation and soil formation on an alluv al-fan piedmont in southern New Mexico. Soi Sci. Soc. Amer. Proc. 30:261-268.

HASTINGS, J. R. and R. M. TURNER. 1965. The changing mile. Univ. Ariz. Press, Tucson, Arizona.

HUMPHREY, R. R. 1958. The desert grassland, A history of vegetational change and an analys of causes. Bot. Rev. 24:193-252.

LIME, D. W. and G. H. STANKEY. 1971. Carrying capacity: maintaining outdoor recreation quality. Recreation Symp. Proc., USDA Fores Serv., North-east Forest Exp. Sta., Upper Darby, Pa., p 174-184.

LOWE, C. H. 1964. Arizona landscapes and habi tats. Part I, pp 1-132 in Lowe, C.H. (Ed.) The vertebrates of Arizona. Univ. Arizona Press, Tucson, Arizona, 270 p.

MAGELL, A. W. and R. H. TWISS. 1965. A guide recording esthetic and biologic changes with photographs. USDA For. Serv. Res. Note PNW- 8 p., illus. Pacific SW Forest & Range Exp. Sta., Berkeley, Calif.

MARSHALL, J. T., JR. 1957. Birds of the pine- woodland in southern Arizona and adjacent Mexico. Pacific Coast Avifauna 32:1-125.

MOIR, W. H. 1972. Natural areas. Science 177 396-400.

MOIR, W. H. and W. LUKENS. 1975. A Natural Re source Monitoring System for Chiricahua National Monument. Unpublished ms. 69 p, tables.

MOSBY, H. S. 1963. Record keeping by means of field notes and by photogrpahy. IN: Wildli investigative techniques, 2nd Ed., The Wildl Soc., Washington, DC, p. 22-31.

PIELOU, E. C. 1969. An introduction to mathematical ecology. Wiley-Interscience , John Wiley & Sons, New York, NY, viii, 286 p.

ROSEBERRY, R. D. and N. E. DOLE, JR. 1939. Th vegetation type survey of Chiricahua Nationa Monument. USDI, National Park Serv., Branch of Forestry, 42 p., illus., map.

STONE, E. C. 1965. Preserving vegetation in parks and wilderness. Science 150:1261-1267.
USDA, FOREST SERVICE. 1974. Outdoor recreation research: applying the results. USDA For. Serv. Gen. Tech. Report NC-9, 113 p., illus., North Central Forest Exp. Sta., St. Paul, Minn.
WAGAR, J. A. 1974. Recreational carrying capacity reconsidered. J. For. 72:274-278.

WHAT WOULD YOU DO WITH, SAY, SAN MIGUEL ISLAND?

Milton C. Kolipinski[1]

THE RESOURCES OF SAN MIGUEL ISLAND

This report describes the animals, plants, archeology, geology and history of 14,000-acre San Miguel Island and 10-acre Prince Island, and recommends actions needed to protect and manage the natural and cultural resources of these islands. The Department of the Navy, under a Memorandum of Agreement in 1963, authorized the Department of the Interior to manage the resources of these islands. The following is a thumbnail sketch of key resources on San Miguel and Prince Islands.

Animals

San Miguel is the only island on Earth where as many as six kinds of marine mammals live together. Heavy hunting in the early 1800's brought some forms nearly to extinction. The populations of most forms have grown considerably but require continued protection. The numbers of some forms are still low but generally increasing.

Two native land mammals, deer mouse and island fox, occur only on San Miguel.

San Miguel has one feral land mammal--the rat. An unknown number of rats roam the island, but their impact on the island ecosystem is unknown.

Thirty-five kinds of birds were observed on San Miguel in 1915. Fewer species were recorded in more recent years. The American eagle nested on the island but disappeared some time before 1963. Visitors sometimes shot at and otherwise harassed the birds but the disappearance of eagles is probably tied in with that of many raptorial birds, apparently caused by persistent pesticides.

The little research done on San Miguel's invertebrate fauna has turned up surprising findings. One scientist found sixteen species of bees! Seven of these were *new species* and five others *new races* of mainland species. Some rare mainland spiders are abundant on San Miguel as well as other of the Channel Islands.

A rich intertidal and underwater life surrounds San Miguel. Few marine areas along the western coast of the United States remain so nearly unspoiled by man.

Plants

San Miguel has about 200 native species, subspecies and varieties of plants. Apparently no form is endemic to San Miguel alone, but a few forms are restricted only to the Channel Islands.

Exotic plants are now common on San Miguel and they have changed the normal composition and successional patterns of the plant communities. A return of plant communities to a pre-grazing-days state is important if San Miguel is to be a natural area.

During much of the year and especially in the spring the ground cover blooms in profusion. The display of wildflowers is often more spectacular than the Southwest desert wildflower blooms.

Archeology

Archeologists have recorded more than 500 archeological sites on San Miguel. These information-rich sites cover at least 8,000 years of human activity. San Miguel is one of the most extensive Indian settlements, of which we have knowledge, on the American continent north of Mexico.

One investigator found an aboriginal cemetery with about 250 skeletons and many utensils, implements and ornaments of stone, bone and shell. The Heye Foundation sponsored a six months' dig which exhumed 343 skeletons. Also in the dig they found tools and ornaments made from bones of the sea lion, deer, and the whale.

Beginning in the early 1870's San Miguel has been a pot-hunter's paradise. Protection by the Departments of Navy and Interior has slowed the pilferage of valuable archeological artifacts from San Miguel.

Geology

Fossil pygmy elephants have been located on San Miguel. The presence of these mammoths and other fossil evidence throws light on the prehistoric development of San Miguel.

What are now the four north channel islands were part of the ancient Cabrillo Peninsula that was part of the California mainland. Even before the Ice Age fluctuating sea levels were creating islands. But a rise in sea level at the end of the Ice Age, some 20,000 to 100,000 years ago, submerged most of the peninsula to its present condition. The high points of the drowned peninsula form San Miguel, Santa Rosa, Santa Cruz and Anacapa Islands.

The geological features comprise much of the island's beauty. The miles of sandy beaches and rugged rocky shoreline, especially viewed from the many steep cliffs, have special aesthetic value.

A curiosity on San Miguel is calcareous structures resembling roots and tree trunks that geologists call caliche. Formed during the Ice Age caliche comes in a variety of weird shapes. In some parts of San Miguel the caliche forms "fossil forests." Tough, case-hardened caliche makes up the ground cover on a bizarre and lifeless-appearing landscape on parts of the island.

Vertical sections from the surface downward through San Miguel provide clues of the island's origin and history. Ancient rocks on the western part of the island are about two miles deep. The rocks found are from sea sediments that were deposited about 60 million years ago.

Oil companies have leased and continue to lease submerged lands for offshore oil and gas development near San Miguel Island. National Park Service remains concerned about possible development of platforms near the island that would degrade the visual environment. Accidental petroleum spills pose potential for possible loss of marine and intertidal natural resources at San Miguel Island.

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Potable water flows on the north and south sides of the island, but little is known about the permeability and related characteristics of the rocks and their capacity to hold and supply fresh water.

History

Juan Rodriguez Cabrillo discovered San Miguel on October 18, 1542. He possibly was buried on the island but no evidence of the burial site exists.

Sea otter and grey whale hunters were active at the Channel Islands in the early 1800's. Simply for sport, some of the hunters reportedly shot the Chumash Indians near San Miguel's shoreline. Shortly after the Indians moved to mainland missions. This ended thousands of years of island occupation by Indians.

In 1848 Mexico ceded all her territory north of the Rio Grande. San Miguel was not part of any land grant and became United States property. Although occupied by squatters and tenants under lease from the United States for periods in its history, the Federal Government has continuously owned the island since 1846. The island became a lighthouse reservation in 1909 administered by the Department of Commerce. In 1934 another Executive Order still in effect today transferred jurisdiction to the Department of the Navy.

In the mid-1850's the island became primarily a sheep grazing range. This catalyzed a change of the island's natural biological communities. By 1862 herds on the island had grown to about 6,000 sheep, 200 cattle, 100 hogs, and 30 horses.

At times since 1942 the Nav-y had used San Miguel as an aerial bombing range and missile target area. In 1965 the Navy sent a team to "sweep the island clean" of unexploded ordnance. Since then, fire has been directed at targets anchored offshore.

THE RESOURCES OF PRINCE ISLAND

Several islets lie just off San Miguel. The most interesting and important of these is steep-cliffed and picturesque Prince Island. Its two greatest values are:

1. Numerous and different kinds of sea birds nest on the island. The cormorant rookery is especially spectacular.

2. The plant communities have remained essentially natural, because sheep never grazed on Prince Island. The plants here can serve as a source for reintroduction of some native forms to San Miguel.

RECOMMENDATIONS

General Introduction and Objectives

This section of the report recommends actions needed to protect and manage the resources of San Miguel Island and its surrounding islets, including Prince Island. The recommendations presented here are based on three broad objectives for San Miguel and its associated islets:

1. Restore and perpetuate cultural features and natural ecosystems.

2. Protect cultural features and native plants and animals from detrimental human activities.

3. Control and, to the extent possible, eliminate non-native plants and animals.

A recent era of devastation of ecological, archeological and historical resources has passed for San Miguel Island. It was characterized by extensive livestock grazing on the land and wholesale slaughter of marine mammals on and near the shore. In recent years much of the primitive character of the island has returned. Irreversible, of course, are the past damages to and losses of archeological sites and historical structures.

The National Park Service in cooperation with the Department of the Navy is developing a management program that will provide for public visitation of San Miguel Island in such manner and by such means as will leave them unimpaired for the enjoyment of future generations.

Some individuals, generally in defiance of posted "no trespassing" signs, enter the island by boat or airplane. Some people, during such illegal visits, either purposely or inadvertently destroy cultural and natural features. By such continuing misuse and lack of adequate protection, the island will continue to suffer losses.

RECOMMENDATION 1. PROTECT HISTORICAL AND ARCHEOLOGICAL RESOURCES

Specific suggestions to protect and preserve San Miguel's historical and archeological values follow:

A. *Protect historical, archeological and paleontological resources from human activities*

Develop an action plan to prevent looters and casual surface collectors from continuing the artifact drain from San Miguel Island. Some dig and cause serious disturbance to sites. Prevention of unauthorized visitors would solve the greatest part of the problem.

The Old Ranch House site represents an example where bottle hunters and other curiosity seekers disturb a historical resource. Vandalism of ruined objects and features continues at the site. Chimney foundations, trash landfill spots, and the collapsed windmill have research potential and require protection. Dwarf mammoth bone sites represent an important paleontological resource requiring protection from human disturbance.

Caliche, described as a unique resource on the island, has not yet apparently suffered noteworthy damage from humans. Nevertheless, this fragile geological resource requires protection from possible vandalism.

B. *Create a survey team of archeologists and paleontologists*

The survey team will identify all archeological sites on the island. Charles Rozaire's map of archeological sites and his site records will be invaluable for this purpose. This team will determine which sites are undergoing destruction by wind and water erosion. Further, it will develop a priority list for salvaging the most important sites first. Sites for investigating the hypothesized man-mammoth associations on San Miguel would likely top the list. Further, the team will identify studies needed to manage and interpret the island's archeological resources.

RECOMMENDATION 2. RE-ESTABLISH NATIVE PLANT COMMUNITIES

A program is needed for re-establishing, to the extent possible, the natural or native vegetation on San Miguel Island with normal distribution

and density of plants. Such a program would restore natural processes of plant succession on the island. Admittedly, this task is difficult. Sparse information exists on the types and distribution of plants on San Miguel Island for the era when European man first visited there over 400 years ago. Nevertheless, the following recommendations will help toward re-establishing natural plant communities on the island.

A. *Study the vegetation of San Miguel Island*

This calls for a thorough review of botanical literature and historical information including aerial photographs of the island. This study will help in determining past and present composition and distribution of plant communities on the island. A map is needed showing locations and areas covered by exotic and native plants. Also, a list is needed of all non-native plants with a species priority for control. Techniques must be developed for eliminating exotic plants. To be effective, the study must result in management recommendations for restoring principal native plants to their normal balance.

Knowledge about marine plants around the island is particularly lacking. Inventories are needed to determine what plants are present and what management actions, if any, are necessary to protect any marine plants or habitats.

B. *Conduct a soils survey of the island*

Maps and other products from this study will be needed for planning and for carrying out native plant restoration projects.

C. *Restore native plant communities*

Restore natural plant cover to the island as recommended in A and B above, after their completion. Meanwhile, information exists for some plant management projects to begin immediately.

D. *Study fire ecology of San Miguel Island*

Man-caused and possibly natural fires have occurred there in historic times modifying natural plant succession and influencing animal populations on the island. Perhaps fire, in some areas, can be used to maintain desired species and to reduce or eliminate exotics. Research can determine the need either for fire or for fire exclusion.

RECOMMENDATION 3. PROTECT PINNIPEDS AND THEIR HABITATS

Pinnipeds represent the most significant and spectacular biological feature of San Miguel Island. The following recommendations focus on restoring populations of these marine mammals to a natural state:

A. *Minimize human disturbance to pinnipeds, especially during the pupping, breeding, and nursing seasons*

The most critical period for the pinnipeds as a whole centers around the months of January through October. Pinnipeds often stampede when felt threatened by humans either from boats, airplanes, or on foot. Pinniped habitats must be kept essentially free of disturbance by regulating all forms of human disturbance. Closure of coves around Point Bennett to sail and power vessels at least during critical months provides one positive step to decrease harassment. Also, low-flying aircraft must be regulated.

By following these measures we can expect: (1) recovery of the northern sea lion population; (2) colony formations of breeding Guadalupe fur seals; and (3) continued growth of the northern fur seal population.

B. *Eliminate commercial capture of the California sea lion and other pinnipeds in the San Miguel area*

In recent years California sea lions have been collected for public display and for use at research institutions. Sea lions have been netted in water or captured on land between Point Bennett and Adams Cove. Because netting is non-selective, it can create stress on several species of seals.

Legitimate commercial needs for California sea lions can best be met from other Channel Islands or mainland areas. On other islands only the pursued species will generally be disturbed during capture.

C. *Encourage research on San Miguel's pinnipeds*

Research should be restricted to only those studies which clearly could not be conducted at any other location. For example, any kind of observational studies, such as studies involving interspecies behavior, would be suitable for San Miguel.

RECOMMENDATION 4. REMOVE FERAL RATS

Rat removal will prove difficult because methods must first be developed for their elimination. Great care will be necessary to avoid damage to the native mouse and fox and to other animals.

RECOMMENDATION 5. MANAGE AND PROTECT NATIVE LAND AND MARINE ANIMALS AND BIRDS

A. *Protect sensitive animal species from human disturbance*

Human presence among sea bird colonies causes loss of eggs and chick mortality. Unauthorized visitors must be kept away from breeding colonies during nesting seasons which run from February through August.

Other animals may require special attention or protection, but this must be determined through research.

B. *Encourage the conduct of animal inventories and population studies*

Animal inventories and population studies are necessary to discover whether problems or potential problems exist for any species. Information is particularly scant on marine animals, excepting pinnipeds, and land animals, especially smaller, less conspicuous forms.

PLANT COMMUNITY RESPONSES TO THE USE OF PRESCRIBED BURNING AS AN ALTERNATIVE TO MOWING IN THE MANAGEMENT OF BIG MEADOWS, SHENANDOAH NATIONAL PARK[1]

W.D. Cocking, E.E. Baxter and S.L. Lilly[2]

Big Meadows exists as one of the few remaining open grassland communities in Shenandoah National Park. Extensive pasture and various stages of old-field succession characterized the vegetation along Skyline Drive when private use was terminated and the park established in 1935. Uninterrupted succession during the forty succeeding years has returned over 99% of the acreage within this long, narrow Virginia park to successional forest. This loss of open plant communities threatens the existence within the park of several plant and animal species due to the reduction of habitat diversity. The major exception to this trend of maturation is the approximately 100 ha tract located across Skyline Drive from the Byrd Visitor Center which is known as Big Meadows. This community, which contains predominantly herbaceous vegetation, has been maintained at an early stage of succession by periodic mowing. Shrub growth is presently so extensive that mowing has been an annual fall management practice for over ten years. This has become an increasingly expensive undertaking, and furthermore, it appears to be stabilizing the community at the shrub-briar stage rather than the more desirable grassland-shrub mosaic.

The decision was made in the fall of 1974 to undertake a limited experimental study of the feasibility of the use of prescribed burning as an alternative management practice to mowing. This paper is a report of the preliminary findings concerning the plant community response to a burn which was carried out on April 17, 1975. These data were gathered during the balance of the summer growing season. This paper will be limited to a discussion of the two management questions which were initially posed: 1. Can the less expensive and more rapidly accomplished prescribed burning be used as a substitute for mowing? 2. Would prescribed burning alter the apparent tendency for the meadow to stabilize at the shrub-briar stage and maintain a more heterogeneous mosaic of vegetation?

Sixteen 0.1 ha plots were studied using a 2 x 2 x 2 replicated factoral experimental design. The three main effects were the presence or absence of the prescribed burn treatment, whether the plot had been mowed the previous fall (1974), and the stage of succession in terms of being predominantly grassland with herbaceous species or shrubland with blackberries, *Rubus* spp., and black locust, *Robinia pseudoaccacia*, as dominant types. Ms. Baxter used a 0.5 m^2 frame which was partitioned into decimeter square sections to estimate cover and Mr. Lilly used 0.25 m^2 above ground clip samples to measure standing crop. These vegetation characteristics were sampled prior to the burn and at several additional times during the growing season. The first complete post-burn samples were taken in May, one month after treatment. Rapid regrowth of vegetation occurred in all burned plots and no adverse soil nutrient loss or erosion effects were observed.[3]

The total biomass of living tissue in the grassland component of the meadow community at three times during the growing season is presented in Fig. 1. Each of the bars represents one of the four management combinations. Considerable variability was evident early in the season due to the discontinuous distribution of *Vaccinium*. Burning significantly reduced the living herbage in both mowed and unmowed communities subsequent to the stress but all treatments returned to approximately control levels by the end of the season.

Biomass data from the shrub community are considered similarly in Fig. 2. It was more difficult to separate living and dead tissue in this community when the April pre-burn samples were taken than it was in the grassland community. Therefore, total living and dead biomass are included and the living proportion is estimated based on values obtained after the stalks leafed-out in May. Significant reductions in biomass were obtained from both mowing and burning which persisted until the end of the growing season. No consistent differences were observed between the treatment combinations for August standing crop. Therefore, burning and mowing appear to be equally effective in reducing shrub-briar growth.

Total vegetation cover in both the grassland and shrub communities is presented for each treatment combination Fig. 3. Values in excess of one meter square vegetation per meter square surface area are explained by layering of the vegetation. These August data represent the maximum end-of-season plant cover since fall die-back began to occur during the month of September. Cover follows the same pattern as biomass in the shrub community and is significantly reduced by both mowing and burning. However, in the grassland,a reduction in cover following burning persists until the end of the season in comparison with the control vegetation, while mowing alone may even increase total plant cover in some cases.

A second year study and more extensive evaluation of the 1975 data will provide additional information concerning the individual species responses to the prescribed burn. Two major trends are already evident. Roughly twenty percent of the cover in the control grassland community is graminoid (*Agrostis tenuis, Calamogrostis canadensis, Dactylis glomerata, Danthonia compresea, Panicum implicatum, P. latifolium, P. linearifolium, Carex argyrantha, C. brevior, C. glaucaudea, C. leptalea, C. tribuloides,* and *Luzula bulbosa*). Figure 4 shows that both mowing and burning tend to increase graminoid cover in the successional communities and illustrates the large difference in species composition between the two seral stages. The second major trend is illustrated in Fig. 5. In this case, the relative cover of the two major briar species in the shrub community is illustrated. *Robinia* and *Rubus* occur in nearly

[1]Research support from the Mid-Atlantic Regional Office of the National Park Service for the extensive field work carried our by Ms. Baxter and Mr. Lilly is gratefully acknowledged.

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[3]Personal communication. Dr. Norman Christiansen, Department of Botany, Duke University, Durham, North Carolina.

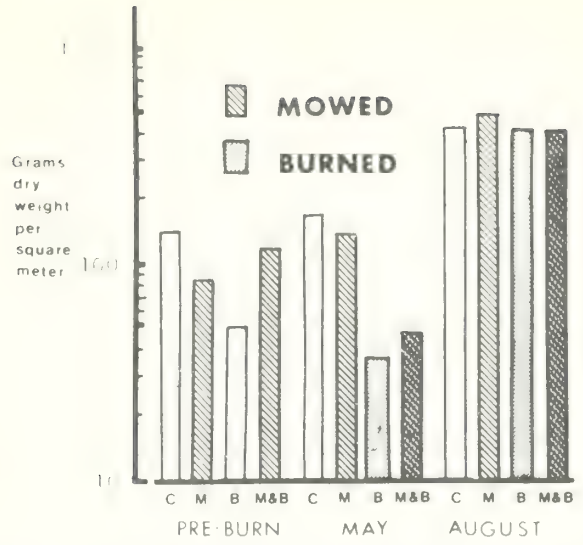

FIGURE 1. Total biamass in the grass dominated community type at Big Meadows, Shenandoah National Park. C = untreated control vegetation; M = mowed in late 1974; B = burned on April 17, 1975.

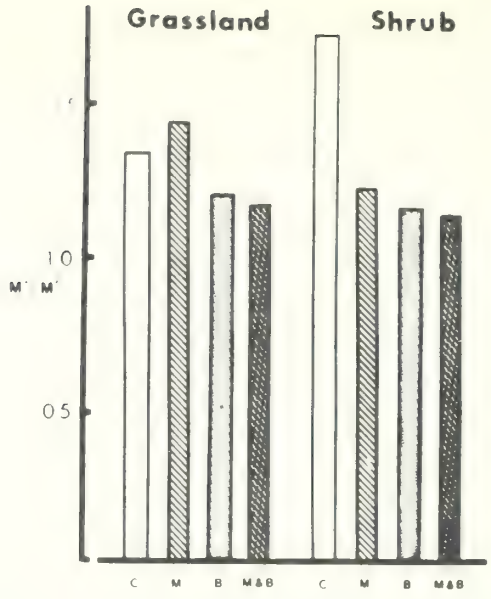

FIGURE 3. Total absolute cover in August in both the grassland and shrub community types at Big Meadows, Shenandoah National Park. C = untreated control vegetation; M = mowed in late 1974; B = burned on April 17, 1975.

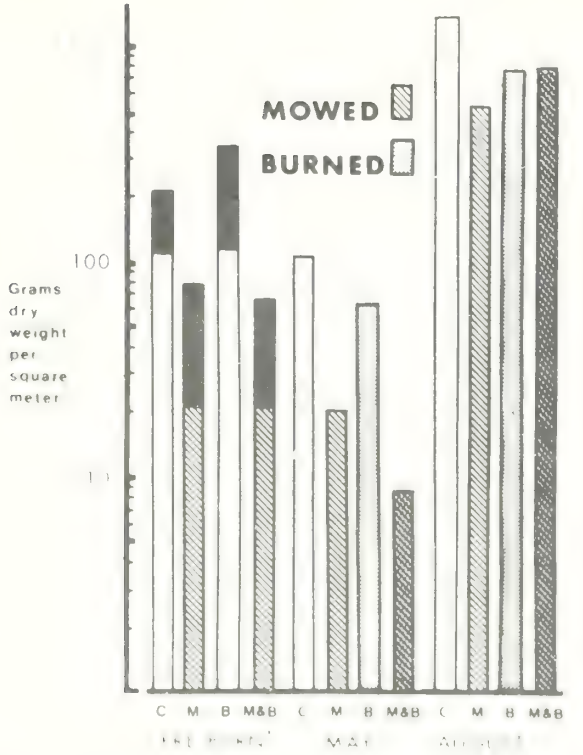

FIGURE 2. Total biomass in the shrub-briar dominated community type at Big Meadows, Shenandoah National Park. C = untreated control vegetation; M = mowed in late 1974; B = burned on April 17, 1975. *The April pre-burn sample includes both living and dead above ground tissues. The amount of dead tissue is estimated by the black portion of the bars.

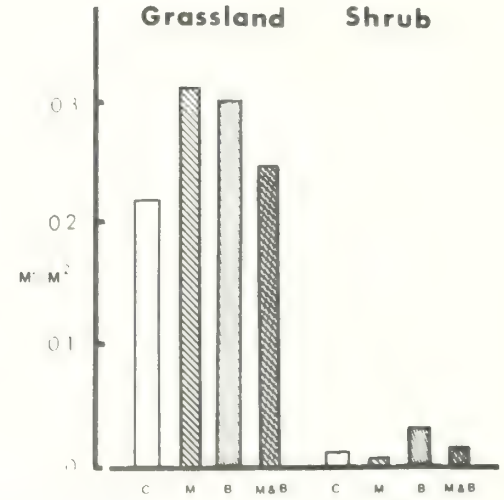

FIGURE 4. Absolute cover in August of the graminoid species in the grassland and shrub-briar community type at Big Meadows, Shenandoah National Park. C = untreated control vegetation; M = mowed in late 1974; B = burned on April 17, 1975.

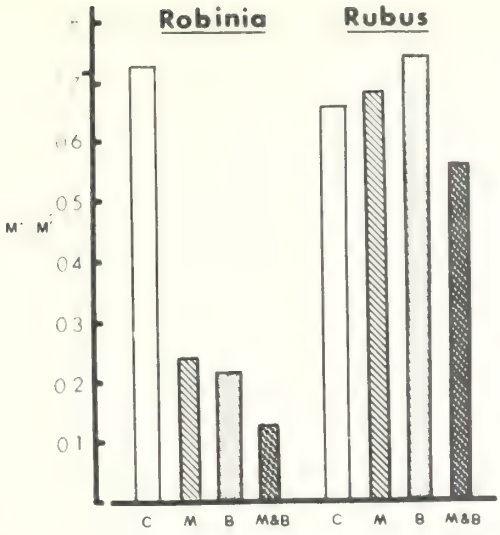

FIGURE 5. Absolute cover in August in the shrub-briar community type of the two major dominant species. C = untreated control vegetation; M = mowed in late 1974; B = burned on April 17, 1975.

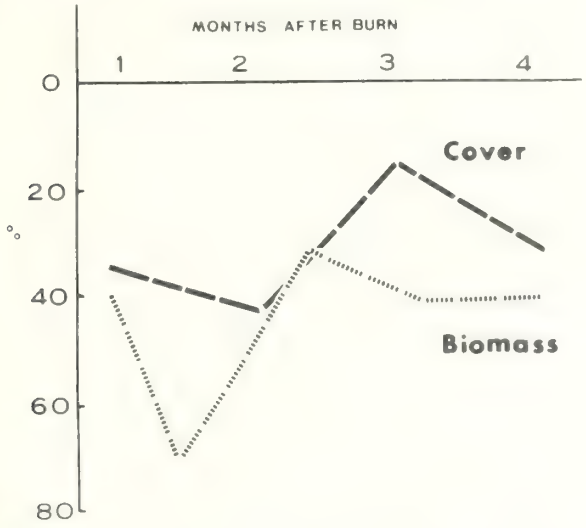

FIGURE 6. Total percent reduction in unmowed shrub-briar community type at Big Meadows, Shenandoah National Park. (Burned vegetation expressed as % of control.)

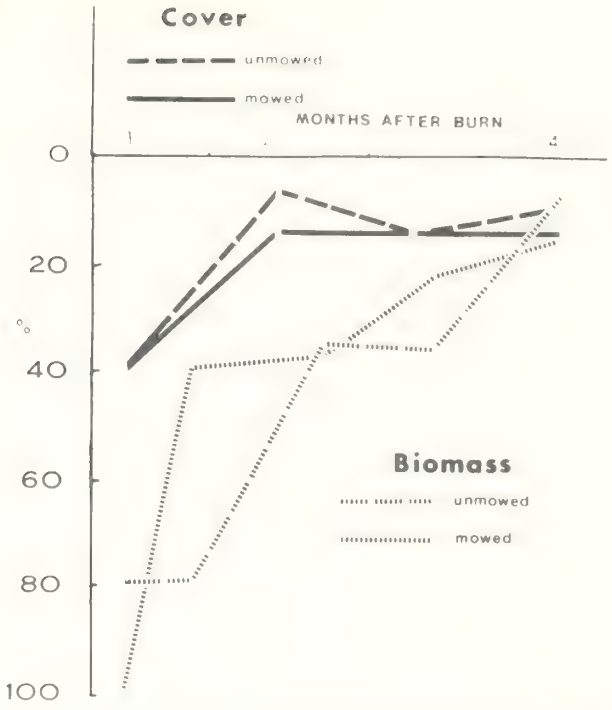

FIGURE 7. Total persent reduction in the grassland type community at Big Meadows, Shenandoah National Park. (Burned vegetation expressed as % of control.)

equal amounts in the unmowed and unburned control plots. A combination of both mowing and burning reduces the *Rubus* cover. However, the end of the season cover following either treatment alone is essentially the same, or possibly greater, than that of the controls. *Robinia* is affected very differently. Both mowing and burning are very effective in reducing black locust cover in contrast to their relative ineffectiveness in controlling the blackberries.

The overall effect of fire in reducing total plant cover and biomass in an unmowed shrub community is shown in Fig. 6. These curves represent the reduction of each as a percentage of the comparable value in the control plots. Maximum reduction of biomass occurred two months after the burn and both cover and biomass remained at 20 to 40% below control levels at the end of the season. A picture of much more rapid reduction in biomass is obtained in the grassland (Fig. 7). Both cover and biomass increased significantly during the balance of the growing season and this is taken as an indication of the repairability of the system.

The management questions can therefore be partially answered. Prescribed burning is very nearly the same as mowing in its effectiveness as a control method for *Rubus* and *Robinia*. Preliminary indications are that there are also relatively few major differences in the impact of the two treatments on other species. The data from the current year (1976) spring burn will be useful in further documenting the individual species responses. Evaluation of the second question is more difficult. The similarity of the responses to burning and mowing indicates that a "fire stabilized" community will also be dominated by shrubs. In this case the species composition may be dominated by *Rubus* spp. Spot treatments within patches of the shrub-briar community such as repeated burns during the growing season, or more severe eradication techniques, may be necessary if a shrub-grassland mosaic is to be maintained.

Burning therefore appears to be a satisfactory and less expensive alternative to annual mowing. However, burning alone is unlikely to be a completely adequate long range management technique.

FIRE MANAGEMENT OF LAVA BEDS NATIONAL MONUMENT[1]

Robert E. Martin and Arlen H. Johnson[2]

INTRODUCTION

Lava Beds National Monument was established in north-central California to preserve an area of exceptional lava flows and lava tube caves and to preserve the site of the 1872-73 Modoc Indian War. The 46,238-acre monument is bordered by Tule Lake on the north and slopes upward into the timber of the Medicine Lake highlands to the south.

A botanist with a railroad survey crew in 1854 gave the first extensive description of the Tule Lake area--bunchgrass plains, sagebrush plains, and ponderosa pine forest, with juniper on rocky outcrops. He indicated fires burned much of the land during dry seasons.

BACKGROUND

This study was undertaken to evaluate the present status of vegetation in Lava Beds National Monument in comparison to historic vegetation; to evaluate fire history and the effect of fire on vegetation; and to develop fire management plans for the monument. Concurrent studies on the responses of mule deer, small mammals, and raptors to prescribed burning are being reported by Dr. Ed Starkey and graduate students from Oregon State University.

Lava Beds National Monument constitutes 46,238 acres (18,720 hectares) of basaltic and pumice soils intermingled with lava flows dating as recently as 500 to 800 years. Elevations range from about 4,000 feet (1,200 m) at Tule Lake to 5,488 feet (1,674 m) on Hippo Butte. The southwest portion of the monument is about 5,000-foot (1,525-m) elevation with many of the volcanic cones extending higher.

The climate is temperate semi-arid with an annual precipitation of 13 inches (33 cm), although a gradient in precipitation can be expected from the high south the the low north. Precipitation occurs primarily during winter and spring; and severe fire weather occurs most frequently during July, August, and September. Mean maximum summer temperatures are 77°F (25°C), and mean minimum temperature in the winter is 24°F (-4.4°C).

VEGETATION

Heavy grazing, western pine beetle, and fire control have probably been the most important factors in changing the vegetation of Lava Beds National Monument. By means of U.S. Army photographs, reconstruction of stands from snags and stumps, and evaluation of the role of fire on plants and plant communities, the historic vegetation (ca 1872) of Lava Beds National Monument was reconstructed by Smathers[3] and Johnson and Smathers[4] and is presented in Figure 1. Recently the vegetation has been mapped from 1974 false-color infrared aerial photographs in conjunction with ground checks. Figure 2 is a simplified version of this map. Army photographs taken in the north end of the monument in 1873 show a bunchgrass plain with shrubs in rocky areas, and no juniper. Today, much of the area is dominated by western juniper (*Juniperus occidentalis* Hook.), sagebrush (*Artemisia tridentata* Nutt.), rabbitbrush (*Chrysothamnus* spp. Nutt.), horsebrush (*Tetradymia canescens* DC.), cheatgrass (*Bromus tectorum* L.) and various forbs. Occasionally, bunchgrasses, particularly bluebunch wheatgrass (*Agropyron spicatum* (Pursh.) Scribn. and Smith) and bottlebrush squirreltail (*Sitanion hystrix* (Nutt.) J. G. Sm.) dominate the grass component, but generally not where the monument has been most heavily overgrazed. Squaw or wax currant (*Ribes cereum* Dougl.) is often present on rocky outcrops.

As we proceed south and upward in elevation, species change. In the 1974 vegetation, sagebrush and rabbitbrush yield to dominant bitterbrush (*Purshia tridentata* (Pursh.) DC.) and curlleaf mountain mahogany (*Cercocarpus ledifolius* Nutt.). Cheatgrass and bluebunch wheatgrass yield to Idaho fescue (*Festuca idahoensis* Elmer).

Open ponderosa pine woodlands dominated the next vegetation zone in 1872. Drought and western pine beetle (*Dendroctonus brevicomis* Lec.) combined to weaken and kill many of these stands in the 1920's, and many sites have been occupied by juniper, mountain mahogany and bitterbrush, creating the juniper-chaparral type now occupying much of the former pine woodland areas. Where remnant pine stands do exist, they are no longer the open stands described by early travelers but often have a dense understory of shrubs and heavy fuel loadings.

The highest sites in the monument are dominated by ponderosa pine with an understory of white fir (*Abies concolor* (Gord. and Glend.) Lindl.) and incense cedar (*Libocedrus decurrens* Torr.). The most common shrubs are snowbrush ceanothus (*Ceanothus velutinus* Dougl. ex. Hook.) and greenleaf manzanita (*Arctostaphylos patula* Greene).

FIRE HISTORY

Fire was probably quite frequent in all of the area occupied by Lava Beds National Monument. The Modoc and Shasta Indians were said to use

[1]We wish to thank the National Park Service, Pacific Northwest Region, Klamath Falls Group, and Lava Beds National Monument staff for their financial support, cooperation, and encouragement during this study. We also wish to thank Dr. James A. Young, ARS, Reno, for advice and bioassays of seeds, and Ron Dougherty, Fire Management Officer at the Doublehead Ranger District, Modoc National Forest, for his support in conducting prescribed burns.

[2]USDA Forest Service, Silviculture Laboratory, Bend, Oregon 97701.

[3]Smathers, G. A. A resources management plan for Lava Beds National Monument. On file at Lava Beds National Monument Library.

[4]Johnson, A. H. and G. A. Smathers. Fire history and ecology of Lava Beds National Monument. Will appear in the Proceedings of the Fifteenth Tall Timbers Fire Ecology Conference.

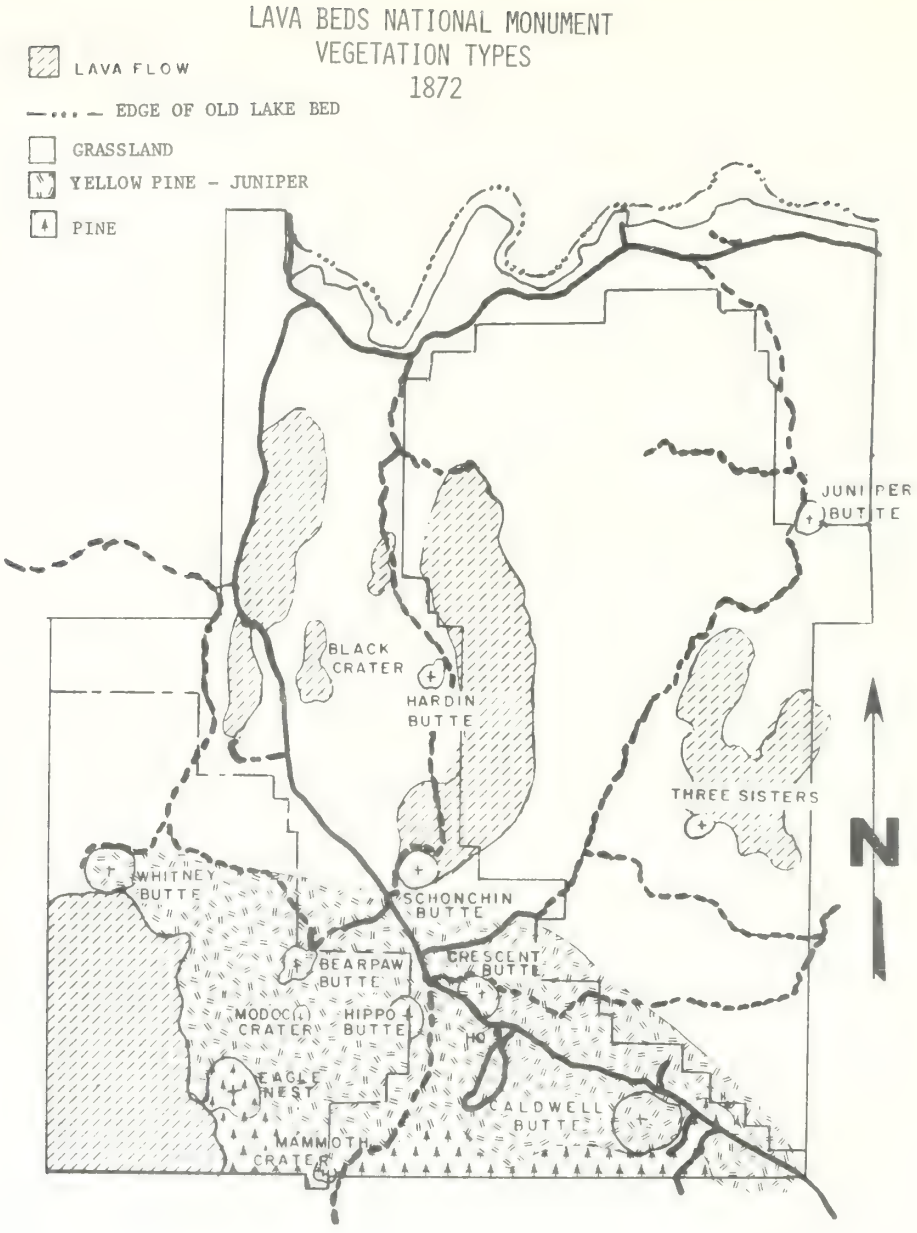

FIGURE 1. Estimate of 1872 vegetation in Lava Beds area (Smathers 1967).

fire in hunting. Their technique was to ring-fire the roughly conical buttes and follow the fire to the top to shoot the escaping game. Undoubtedly, many of these fires later spread over the area.

Lightning fires are a common phenomenon in this region, and Buck and Schroeder (1970) indicate 21 to 40 lightning fires per million acres per year. In 43 years of monument records, 76 of 113 fires (67 percent) have been lightning caused. This amounts to 1.8 lightning fires per year on the monument or one fire for every 26,000 acres each year. Almost half (45 percent) of the lightning fires are in July with all others distributed between May (16 percent), June (9 percent), August (14 percent), and September (16 percent). In addition to fires starting on the monument one would expect many fires originating outside the monument area to spread into it.

Scarred snags provide at least a partial record of prehistoric fires (Table 1), with periods

TABLE 1. Average periods between fire scars on 66 snags in Lava Beds National Monument.

Area	Period between scars (years)
East Caldwell Butte	7.3
Caldwell Butte	9.6
South of Caldwell Butte	11.0
Bearpaw Butte	11.0
Hippo Butte	13.0
Crescent Butte	13.0
Eagle Nest Butte	13.0
Crescent to Red Butte	17.0

FIGURE 2. Lava Beds vegetation in 1974 as mapped from false-color infrared aerial photographs.

between scars of 7.3 to 17 years. Often an increase in the period between fires will be apparent as elevation increases. The slight elevation changes recorded here would give only a slight indication of this tendency. The actual period between fires should be less than indicated by the scars since not all previously scarred trees are again scarred by fire.[5] Until we can develop a more comprehensive fire history for the area, we will assume a fire periodicity of 5 to 15 years.

EFFECTS OF FIRE ON VEGETATION

Because of heavy grazing, pine beetle, drought and fire control, vegetation has changed drastically from that which existed prior to European incursion into the area. A series of prescribed burns were begun in 1974 to develop vegetation responses on documented fires. The two 1/5-acre (.08 hectare) fires in 1974 were too small to yield significant data, so only 1 year's results from several 1975 burns are available. In 1976, two areas of 354 and 410 acres (143 and 166 hectares) were burned, providing larger and more diversified fires for studying both plant and animal response.

The general effect on succession in various habitat areas can be derived from the Lava Beds prescribed burns, our previous experience, and the literature (Figure 3). The diagrams are oversimplified as many alternatives could occur due to climatic, vegetational, or seasonal variations. Basically, fire either holds succession at a pioneer or seral stage or moves succession backward to an earlier stage. Fire can also move succession forward, but this is not indicated here. In each of the vegetative types indicated here, fire would tend to move succession to or hold it in what we believe to be the desired historic vegetation. Problems arise particularly in two places: 1) areas where cheatgrass has

[5] Arno, S. Fire history in Bitteroot National Forest. Unpublished.

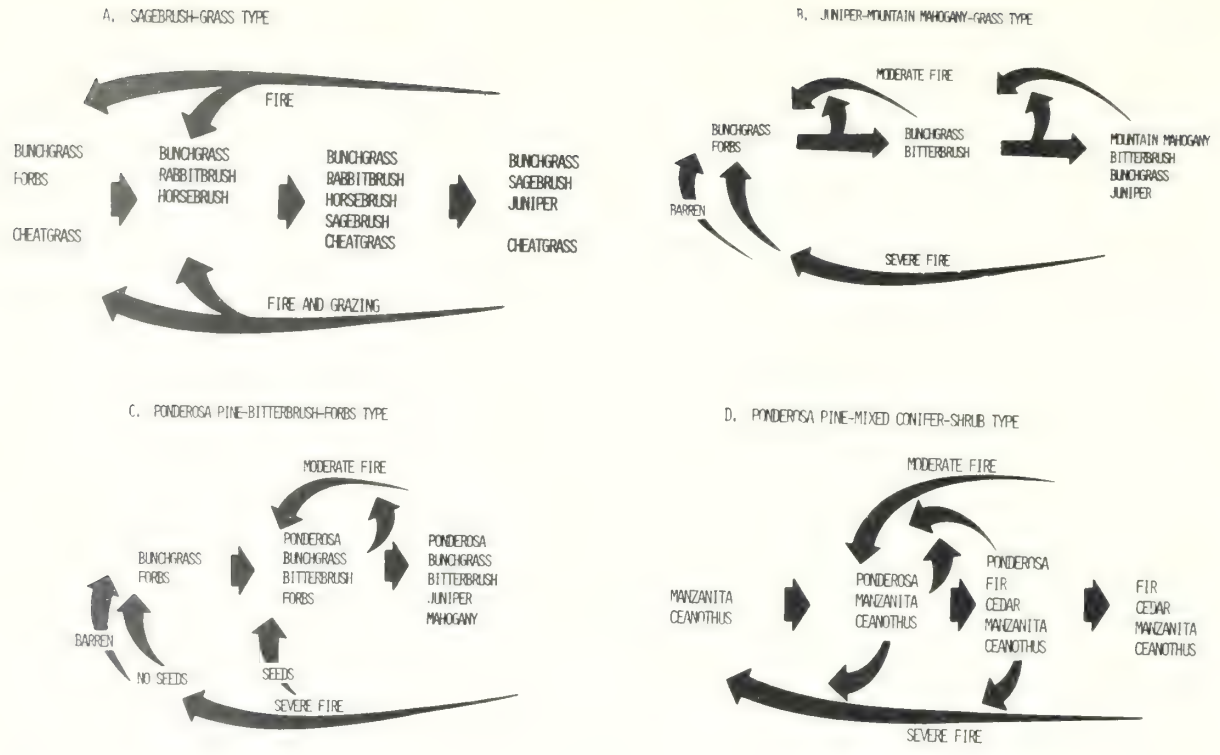

FIGURE 3. Role of grazing and varying intensities of fire in four general bahitat zones of Lava Beds National Monument. Ecological procession proceeds from left to right, but fire and grazing may retard, reverse, or advance for process.

invaded and native rabbitbrush proliferated after grazing destroyed the native bunchgrasses; 2) areas where pine was killed by western pine beetle. We know burning and chemical treatment can reduce cheatgrass so that seeded bunchgrasses can become established (Young et al. 1970). Young et al. (1976) have also found that cheatgrass germination following wildfire is directly related to the amount of unburned duff remaining following fire. We have burned immediately after cheatgrass curing and reduced cheatgrass density from an average of 8,108 to 2,448 plants per square meter with germination reduction from 7,220 to 645 per square meter (Table 2). This reduction is deemed inadequate, however, to create growing space for new bunchgrasses. Rabbitbrush sprouts readily following fire and may also be a problem in these areas.

Another problem arises in the reestablishment of ponderosa pine in areas where it was lost due to drought and insects. Prescribed fire will reduce competition from shrubs and prepare an adequate seedbed.

TABLE 2. General effects of fire on several common plants of Lava Beds National Monument.

Plants	Effects
Grasses	
Bunchgrasses	Cover reduced 30-40 percent first year. No reduction in density except in August burn; *Sitanion hystrix* very apparent after burns
Cheatgrass (*Bromus tectorum* L.)	Density reduced from average 8,108 stems/m^2 to 4,758 stems/m^2 after one June burn and 2,448 stems/m^2 after two June burns; seed germination reduced from 7,220/m^2 before fire to 4,595/m^2 after 1 fire to 645/m^2 after 2 fires
Herbs	
White stemmed mentzelia (*Mentzelia albicaulis* Dougl. ex Hook.)	Appears in profusion following fire in mountain mahogany and bitter brush
Alfilaria or filaree (*Erodium circutarium* (L.) L'Her.)	Increases from seed following burns
Rabbitbrush goldenweed (*Haplopappus bloomeri*)	Sprouts following fire
Shrubs	
Sagebrush (*Artemisia tridentata* Nutt.)	Generally killed by fires; may withstand very light burn

Plants	Effects
Rabbitbrushes (*Chrysothamnus* spp. Nutt.)	Both *C. nauseosus* and *viscidiflorus* sprout rapidly after burning; they can be expected to occupy more of site due to sprouting and seedlings.
Horsebrush (*Tetradymia canescens* DC.)	Sprouts following fires.
(*Ribes* spp. L.)	The currants and gooseberries sprout readily following fire.
Bitter cherry (*Prunus emarginata* (Dougl.) Walpers)	Sprouts readily after and even after very intense wildfires.
Bitterbrush (*Purshia tridentata* (Pursh) DC.)	Up to 30 percent of plants may sprout after light fire with good soil moisture; many sprouts die by 2nd year. Regenerate from squirrel seed caches.
Curlleaf mountain mahogany (*Cercocarpus ledifolius* Nutt.)	Killed by most fires; possible to survive very light fires.
Greenleaf manzanita (*Arctostaphylos patula* Greene)	Killed by most fires; will sprout after very light fire; seed dormancy broken by fire.
Snowbrush ceanothus (*Ceanothus velutinus* Dougl. ex Hook.)	Sprouts readily after almost all fires; seed dormancy broken by fire.
Trees	
Ponderosa pine (*Pinus ponderosa* Dougl. ex Loud.)	Benefits from moderate fires; very resistant; survival increases with tree size; fire prepares seedbed, may reduce competition, reduces heavy fuel loads.
Knobcone pine (*Pinus attenuata* Lemm.)	Fire will kill all except largest trees; fire will open serotinous cones.
Sugarpine (*Pinus lambertiana* Dougl.)	Large trees resistant to moderate fire; fire will prepare seedbed, reduce competition and heavy fuel loads.
Western white pine (*Pinus monticola* Dougl. ex D. Don)	Similar to sugarpine.
White fir (*Abies concolor* (Gord. ex Glend.) Lindl.)	Very sensitive to fire; very tolerant and will take over mesic pine sites without fire.
Incense cedar (*Libocedrus decurrens* Torr.)	Old trees resistant to fire; young killed by light fire.
Western juniper (*Juniperus occidentalis* Hook.)	Old trees resistant to fire if crown not scorched.

The seed source has been lost from extensive areas, however, and reestablishment by natural means will be very slow. An alternative could be to collect seeds from local trees and either broadcast seed or plant seedlings in a random pattern. The last alternative would probably result in the most rapid pine establishment.

The effects of fire on plant species often depend on the conditions of the burn: season, period between burns, weather, vegetation condition, and seed availability (Table 2). More detailed data on response of these species as well as other species is presently being developed. We might also list plants as increasers, decreasers, or conditional responders to fire:

Increased by almost all fires	Decreased by almost all fires
Rabbitbrush	Sagebrush
Horsebrush	Bitterbrush
Alfilaria	Mountain mahogany
Haplopappus	White fir
Mentzelia	Juniper
Ceanothus	Incense cedar

Response intermediate or dependent on conditions

Bunchgrasses
Cheatgrass
Ribes
Bitter cherry
Manzanita
Ponderosa pine
Knobcone pine
Western white pine
Sugar pine

PRESCRIBED BURNING CONDITIONS

We are still in the process of refining prescriptions to accomplish various objectives, and we expect the refinement to continue for several years. The conditions presented in Table 3 generally describe the successful burns we have conducted or which we feel will work. In using these, one should not use the highest winds with the lowest relative humidities and fuel moistures, otherwise he may end up with a much more intense fire than he intended. Similarly, if one used the lowest winds with the highest relative humidities and fuel moistures, the fire may not spread at all. The objectives of the burn as well as condition of the stand should also influence the type of burning done. Other steps in prescribed burning, such as obtaining weather forecasts, posting weather watches, and starting a test fire, can be found in prescribed burning guidelines (Mobley et al. 1973; Martin et al.[6]).

FIRE MANAGEMENT PLANNING

The final objective of our study is to develop fire management plans for the monument. As with fire history and ecology, these plans will be refined and modified as better data are developed. Several factors must influence the fire management plan:

1) Management objectives.

2) The effects of different kinds of fire on flora and fauna.

[6]Martin, R. E. et al. Preliminary prescribed burning guidelines for eastern Oregon and Washington. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon. In Press.

TABLE 3. General fire prescription parameters for vegetation types at Lava Beds National Monument.

Dominant plants	Wind		Relative humidity	Fine fuel moisture for dead fuels	Season
	Miles per hour	Kilometer per hour	percent	percent	
1. Sagebrush, rabbitbrush, horsebrush, bunchgrasses, cheatgrass					
a. Much dead woody fuel	7-12 Gusts to 15	11-19 Gusts to 24	20-25	5-15	Spring Early summer Fall
b. Little dead woody fuel	Same	Same	15-25	5-12	
2. Cheatgrass	3-12 Gusts to 15	5-19 Gusts to 24	20-30	8-13 Duff should also be dry	June burn will reduce seed load
3. Bitterbrush, mountain mahogany					
a. Much dead woody fuel	1-7 Little gusting	2-11	25-35	6-12	
b. Little dead woody fuel	5-10 Gusts to 12	8-16 Gusts to 19	20-25	5-10	
4. Ponderosa pine, fir, cedar bitterbrush, mountain mahogany, ceanothus, manzanita					
a. Much dead woody fuel and needle drape	3-7 in stand	5-11 in stand	30-60	8-12	Avoid midsummer
b. Little dead woody fuel and needle drape	1-10 in stand	2-16 in stand	20-50	5-12	Anytime once stand in condition

►

3) Historic vegetation and historical evidence of fire.

4) Areas sensitive to fire or that must be protected, such as headquarters area, campground, other improvements, and surrounding ownerships.

5) Resources available to accomplish tasks or to provide fire protection.

We have tried to take each of these into account as we develop a fire management plan.

Based on National Park Service policy, the objectives of management for the monument are to preserve or restore the historic scene in as natural and unobtrusive way as possible. Fire prescribed to manipulate the vegetation toward the historic vegetation will be a major tool. Other means, such as drilling or planting, may be necessary if we are to develop the historic scene in a reasonable amount of time.

Several areas are sensitive to fire or must be protected from fire to various degrees (Figure 4):

Area	Requirements	Recommendation
Headquarters	Complete protection	Maintain watered grass with rock and native shrub landscaping to 50' or reduce fuels in early summer; in next 100', keep fuel load low
Campground	Complete protection	Campers have kept fuel low; inspect in spring for tongues of fuel leading into campground area; maintain fire break or fuel break around campground
Historic sites	Protection of flammable structures and signs	May be isolated from prescribed burns

Precipitation	Firelines	Firing patterns
One or more days after significant rain if fall burn	Burn out to at least 200 ft. (60 meters) on downwind side	Strip headfire Headfire Ring fire
Sufficient time for duff to dry	Burn out to 50 ft. (15 meters) on downwind side	Strip headfire Headfire Ringfire
	Burn out to 50 ft. (15 meters) on downwind side; then proceed slowly, depending on wind and fuel moisture	Backfire Strip headfire Ring fire Strip headfire Ring fire
One or more days following significant fall rain	Slowly widen lines with backfires and strip headfires	Backfire, strip headfire, flame fire. Once stand in condition can also use headfire.

Area	Requirements	Recommendation
Northeast boundary Private homes	Complete protection	Develop fuel break and/or fire break along "Big Creek"; discuss with land owners
Tule Lake sump and wildlife refuge	Cooperative fire management	Develop joint fire plans with Fish and Wildlife Service
Northwest boundary Grain fields and wildlife refuge	Restrict burning periods Cooperative fire management	Avoid burning July to Sept. when grains cure; joint plans with Fish and Wildlife Service
West boundary Grazing permits and bighorn sheep pen	Cooperative agreements and coordination with bighorn sheep advisory committee	Develop joint plans with Forest Service for rotation grazing; burn only small part of pen at one time
South boundary Forest Service and International Paper timberland	Cooperative fire management	Develop joint agreements for fuelbreaks along Tichnor Road using prescribed burning
Southeast boundary Forest Service grazing permits	Cooperative agreements	Develop joint plans with Forest Service

At the same time provisions are made to protect these sensitive areas, we recommend a prescribed burning program be undertaken to help restore vegetation to its historic condition. Prescribed burning will also reduce fuel loadings and the potential for catastrophic wildfires. The prescribed burns conducted thus far constitute only a small percent of the monument area (about 2 percent) and do not significantly reduce potential wildfire spread. Priority areas for the next prescribed burns should be (Figure 4):

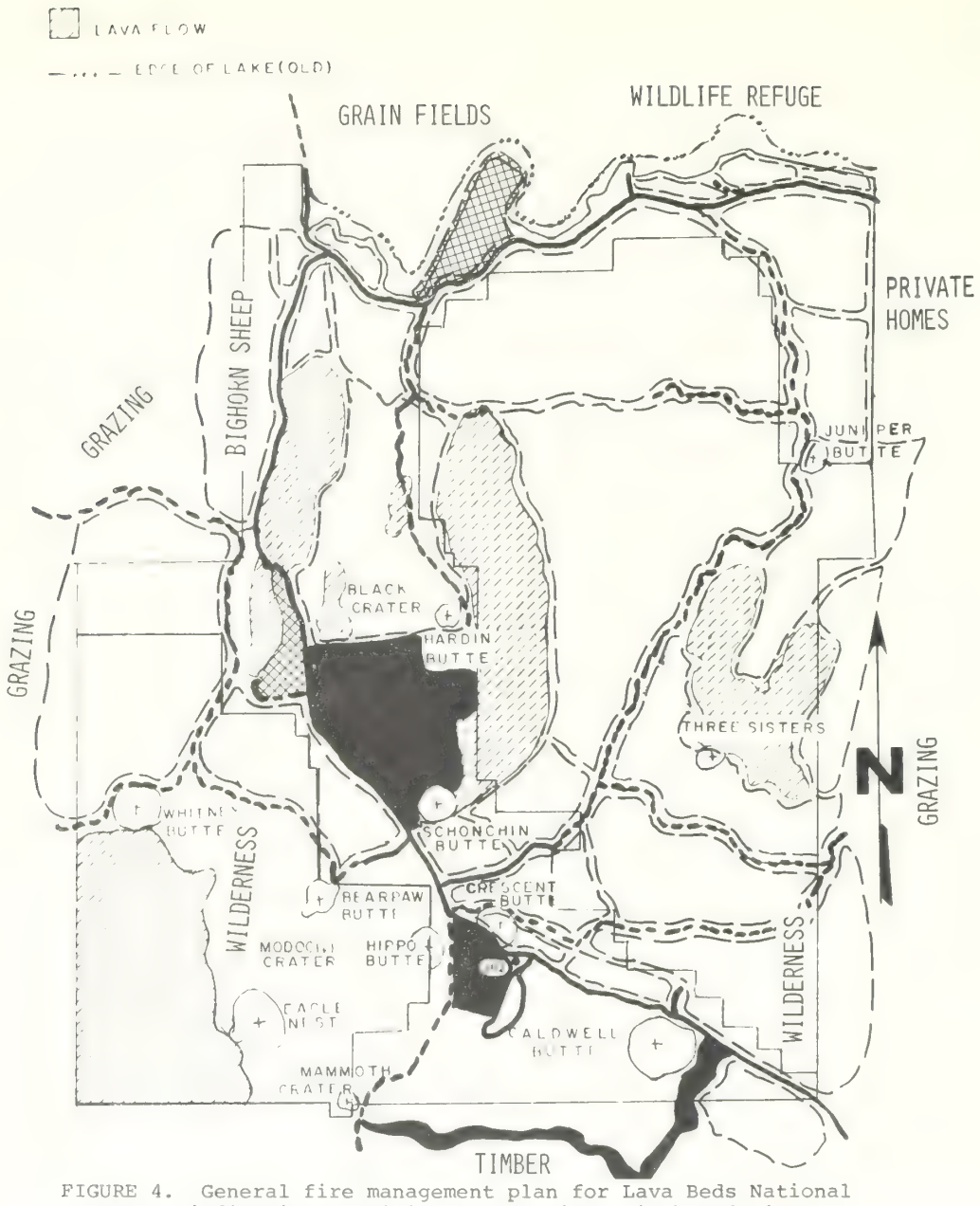

FIGURE 4. General fire management plan for Lava Beds National Monument, indicating sensitive areas, fire unit boundaries (— —), and priority prescribed burning areas (black). The large area in the southwestern part of the monument has not yet been divided into units. Crosshatched areas are the large prescribed burns conducted in 1976.

a) Fuelbreak burns in the area of Tichnor Road. These burns will range in size from about 3 acres (1.2 hectares) to almost 100 acres (40 hectares); but the areas are generally isolated by roads, skid trails, old railroad grades, or collapsed lava tubes. Little fireline building will be necessary, and burning should be in cooperation with the Modoc National Forest.

b) Mountain mahogany-bitterbursh area just west of headquarters. This area of high fuel loading is just west of and leads to the headquarters area.

c) Area west of Schonchin Butte. Burning of this area would isolate many fires in north end of monument from the heavy fuel loads in the south end.

Beyond the three areas discussed above, all of which will further enhance research on the effects of fire on vegetation and fauna, many other units are distinguished by ready-made fuelbreaks or firelines (Figure 4). The detailed management plan now being prepared will describe these in greater detail by vegetation, fuels, area, boundaries, lengths of firelines needed, as well as prescribed burning recommendations. In arriving at frequency of burning, the plan can provide for a standard rotation for different areas of, say, 5 to 15 years with other areas not burned at all, or for a random selection of burning units in any given year or period of years.

We should mention, as one looks at the relatively large size of some units, that we would not expect a complete burn in large units, due to variation in fuels and to rocky outcrops. The unburned islands within these burned areas will

provide variability in habitat and scenic variety.

SUMMARY

In this paper, we have presented the historical and ecological role of fire in Lava Beds National Monument. Based on fire's role, management objectives, sensitive areas, and the potential use of prescribed burning, we have outlined a fire management plan for the monument. A detailed plan is being prepared, and modifications to it will be made as better data are developed.

LITERATURE CITED

BUCK, C. C. and M. J. SCHROEDER. 1970. Fire weather. USDA For. Serv. Agric. Hdbk. 360. 299 p.

MOBLEY, H. E., R. S. JACKSON, W. E. BALMER, W. E. RUZIUSKA and W. A. HOUGH. 1973. A guide for prescribed fire in southern forests. USDA For. Serv. Region 8, Atlanta, Georgia. 40 p.

YOUNG, J. A. and R. A. EVANS. 1970. Weed control in wheatgrass seedbeds with siduron and picloram. Weed Sci. 18(5):546-549.

YOUNG, J. A., R. A. EVANS, and D. A. WEAVER. 1976. Estimating potential downy brome competition after wildfires. J. Range Mgt. 29(4):322-325.

SPATIAL AND TEMPORAL DISTRIBUTION OF NATURAL FUELS IN GLACIER PARK[1]

Bruce W. Jeske and Collin D. Bevins[2]

INTRODUCTION

Quantification of natural fuel distributions is necessary to effectively utilize available fire potential and behavior models to aid in wilderness fire management decision making. An analysis of over 400 fuel samples taken in Glacier National Park shows ground fuel loads and packing ratios can be differentiated to primary succession-land form type categories, temporal secondary succession categories, and three vertical fuel-vegetative strata.

Glacier's ground fuels can be stratified by vegetative-land form type into five primary succession categories: upright forest, Krummholz forest, shrubfield, prairie, and meadow. Upright forest fuel arrays are further classified by twenty and fifty year interval stand age classes. Fuel array packing ratios were also found to be discrete in their vertical distribution for each fuel category and class. Three vertical fuel-vegetative strata are recognized: the compacted needle-fall and undecomposed organic matter, the stratum of fallen stemwood and branchwood and non-woody vegetation, and an upper layer of the supported woody stemmed vegetation. During the sampling and analysis, eleven fuel array components were considered: fallen woody stems and branchwood in four diameter size classes, forest floor litter, non-woody vegetation, the stemwood and foliage components of woody-stemmed vegation, and packing ratios of three strata.

SAMPLING PROCEDURE

The fuels data were collected in Glacier National Park in the summer of 1975 by two Gradient Modeling Inc. field crews. Sampling was for eight fuel types: litter, grasses and herbs, shrub foliage, shrub stemwood, and four moisture time lag classes of dead, fallen branchwood. Time lag is the time required for a dead woody fuel to gain or lose 1-1/e of its moisture content with respect to an equilibrium moisture content (Fosberg 1970). It can be conceptualized as the time needed for a fuel particle to respond to a change in the ambient humidity. The four time lag classes of 1,10,100, and > 100 hours correspond to fuel particle diameter size classes of less than 0.64, 0.64-2.54, 2.55-7.62, and greater than 7.62 cm, respectively.

Each fuel plot was coded for site and stand characteristics to determine the location of the sample within an environmental gradient matrix. A 0.01 hectare quadrat was used to sample the overstory vegetation. Fuels were sampled at two randomly located 'stations' per plot, using three assessment techniques. The planar intercept method (Brown 1974) was used to sample the fallen branchwood. Litter and herbaceous fuels were destructively sampled from circular $0.1m^2$ subplots and returned to the lab to obtain oven dry weights. Shrub stems were tallied by species and stem diameter size class within two $1.0m^2$ subplots, and later converted to foliage and stemwood loads using biomass regression equations. The layout of the plot, its subplots, and sampling planes is illustrated in Figure 1. The information recorded at each plot is summarized in Figure 2.

ANALYSIS METHODS

Analyses were first performed on 431 sample plots using a primary succession stratification. Each plot was identified by its soil-site development and vegetation growth forms as belonging to one of nine primary succession categories: glacier, rock, talus, talus-meadow, meadow, prairie, shrubfield, Krummholz, or typical upright forest. The 218 forested plots were further stratified into fire history (secondary succession) age classes by years since major burn disturbance. Fuel array characteristics were examined by two distinct age classification schemes, one with twenty year intervals (<45, 45-70, 70-90, 90-110, . . . 170+ years since burn) and another with fifty year intervals (1-55, 56-105, 105-155, 155+ years since burn). The length of time since evident burn for each plot was determined from fire history records and from on site overstory increment cores. Dating accuracy was within approximately ± 5 years.

Forested plots were also divided into mesic and xeric types based upon overstory indicator species. Kessell (1974) found *Tsuga heterophylla, Thuja plicata, Picea spp.*, and *Populus trichocarpa* to prefer low elevation, moist sites in Glacier National Park. Forested fuel plots in stands where one of these species was common or abundant was designated as 'mesic' for purposes of stratification. All other forested plots were considered 'xeric.'

Within each stratification, eleven fuel array characteristics were examined. They include fuel loads for litter, grass and herbs, four time lag classes of dead fallen branchwood, shrub foliage, and shrub stemwood. Packing rations were also calculated for three fuel-vegetation strata: (1) litter, (2) grasses, herbs, and fallen branchwood, and (3) shrubs. The packing ratio (ratio of fuel volume to fuel bed volume) indicates the compactness of the fuel bed and determines, to a large degree, the potential fire behavior on the site (Rothermel 1972). The frequency distribution of each characteristic was analyzed for its mean, median, skewness, and standard deviation within each stratification grouping. The results were then examined for trends between primary succession categories, along years since burn intervals, and between 'mesic and xeric' forested sites.

[1]The authors would like to acknowledge the industrious and personally motivated people that worked on field crews throughout the summer of 1975. Glacier National Park displays some of the most spectacular scenery in the Northwest. It is difficult to enjoy the grandeur of such a place with your nose one foot above the ground counting twigs and collecting bags of forest litter. It took personable and scientific minded people to tolerate long hours of rain, biting insects, trail food, scanty payment, and close living quarters to collect these data--people who worked with the feeling that their time was spent to increase a body of knowledge which managers can utilize to make more sound decisions in management of our most precious wildlands.

[2]Missoula Office, Gradient Modeling, Inc., Missoula, Montana 59806.

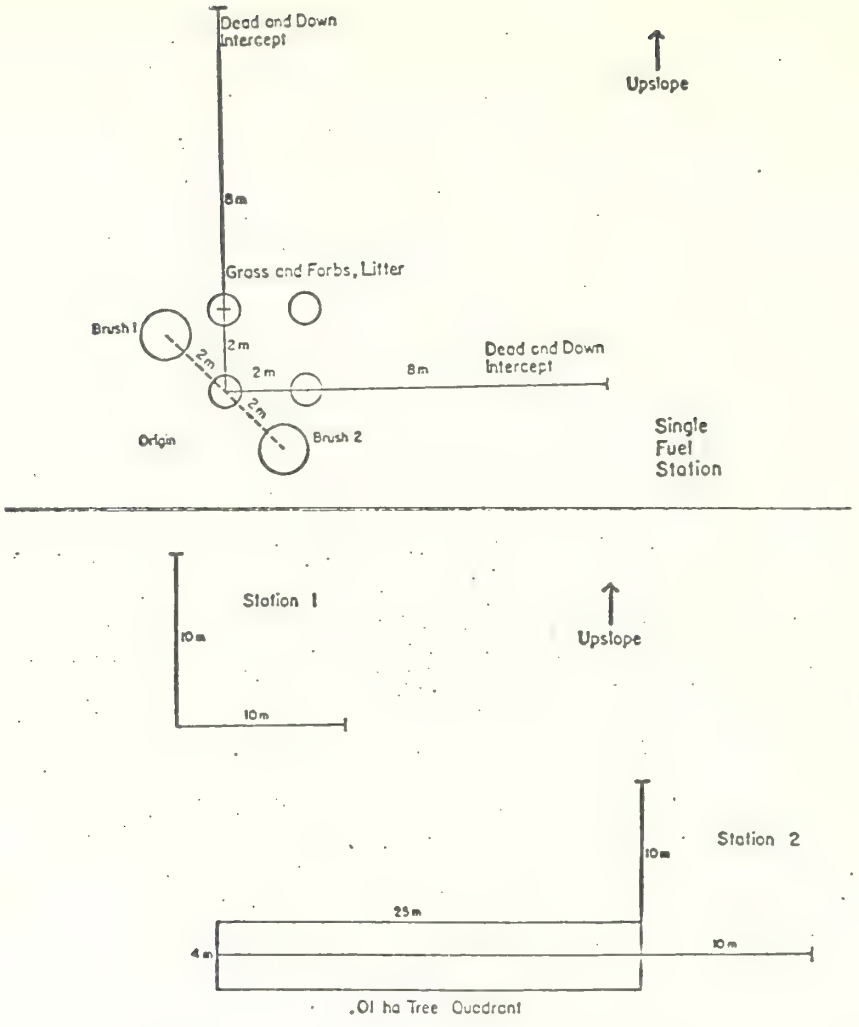

FIGURE 1. Standard 2 station fuel sample.

Site coding	1. UTM coordinates 2. Cover type 3. Elevation (feet above MSL) 4. Topography type (bottomland, slope, ravine, etc.) 5. Aspect (nearest 10^{o}) 6. Terrain slope (nearest 1^{o}) 7. Burn history of the stand 8. Drainage code 9. Alpine wind/snow effects
Cross and upslope	1. Duff depths (cm) 2. Heights of dead and down woody material (cm) 3. Number of dead and down fuel particles intersected by sampling plane for each fuel category
Grass and forbs subplots	1. Height (cm) 2. Cover (estimated percent) 3. Condition (estimated percent) standing live green herbs)
Litter subplots	1. Depth (cm) 2. Cover (estimated percent)
Shrub subplots	1. Height (cm) 2. Cover (estimated percent) 3. DGH by species (diameter ground height in cm)
quadrat	1. DBH by species (cm) 2. Canopy cover (estimated percent) 3. Height to lowest live branch (dm) 4. Height of highest ground fuel (dm) 5. Relative tree species abundance within the stand

FIGURE 2.

RESULTS

Results from the preliminary data analysis are summarized in the following tables and figures. Within each stratification group, the frequency distributions for all eleven fuel characteristics showed a tendency to be skewed to the right. Ratios of the median to the mean nominally ranged from 0.4 to 0.8. Small fluctuations are found in most of the curves in the far right hand tail. These secondary modes are the values from a few plots taken in localized areas of abnormally high fuel loads. Such 'jackpots' may be caused by ice damage, windthrow, disease or insect infestations, avalanche activity, or sharp topographic discontinuity. Due to the non-continuous nature of natural fuel beds, these few data points tend to aggravate the skewness by raising the mean for the distribution, moving it further to the right. In this case, medians are more indicative of the central tendency of a population, and are used in the subsequent analysis.

DISCUSSION

Table 1 shows the changes in median fuel loads and packing ratios along the primary succession stratification. As expected, litter and the four size classes of fallen branchwood show an increase from talus to forest. Litter increases from 0.2 and 0.6 T/Ha in meadows and prairies, to 2.2 T/Ha in typical forests, an eleven fold increase. Litter loads in typical forest are 20% higher than in shrubfields and 75% above the 1.3 T/Ha measured in Krummholz. Grass and herb biomass is highest in prairies at 1.4 T/Ha. As sites become more capable of supporting a shrub canopy, loads drop to 0.4 T/Ha, and even further to 0.2 tons in upright forest. Between the shrubfields and forest types 1 hour fuels exhibit a 60% increase from 0.5 to 0.8 T/Ha. The 10 and 100 hour fuels do not vary appreciably between the shrubfield, Krummholz, and upright forest primary succession categories. Greater than 100 hour fuels show a notable increase of 100% from shrub to Krummholz and an additional 25% increase in upright forest with 20 T/Ha. Shrub foliage and branchwood are highest in the Krummholz at 1.7 and 8.5 T/Ha respectively, and decrease to about one fifth of these values in forest. All trees less than 5.0 cm DBH are considered part of the shrub layer, accounting for the apparent high shrub loads in the Krummholz. Packing ratios for the three strata follow similar trends as their respective fuel load components.

Tables 2 and 3 summarize the responses of fuel loads and packing ratios to post-fire succession. Plots sampled in the 1-10 years since burn category were taken on sites where fire destroyed more than 90% of the overstory. Litter and 1 hour branchwood were removed by the fire and have very low loads at this time. Loads of 10, 100, and > 100 hour branchwood are quite high (2.8, 6.0, and 27.8 T/Ha, respectively) as snags damaged in the burn fall to the forest floor, adding to the existing large ground fuels not consumed by the fire. Shrubs, herbs, and grasses flourish at this time due to increased sunlight and enriched, exposed mineral soil seedbed. Shrub loads, including tree seedlings, total 4.9 T/Ha; grasses and herbs are 0.5 tons.

As the stand succeeds from the 10 year post-burn level, the median loading values generally exhibit three types of behavior. Certain fuels tend to decrease through time, others plateau at a particular level and remain relatively constant, and others tend to accumulate. The live fuels, shrubs and herbaceous material, decrease as the stand matures. As the canopy closes, loadings for grass and herbs decrease 40% and continue this decline to 0.2 T/Ha at 155 years and older. Total shrub loads show a 40% decrease at stand closure, remain fairly constant from 70 to 150 years, and finally drop at 155 years to 0.2 T/Ha for shrub foliage and 0.7 tons for shrub branchwood, an 80% decrease from the post-burn level. Litter and 1 hour fuels tend to increase and then plateau from canopy closure to maturity. Litter remain near 2.2 T/Ha, except for an increase around 150 years, due likely to high *Pinus contorta* mortality. The 1 hour fuels reach 1.1 T/Ha and show no tendency to accumulate through maturity. The 10 hour fuels drop to one half of the level resulting from snag deposition, and remain close to 1.4 T/Ha, with a slight tendency to increase towards maturity. 100 hour fuels show a rather erratic behavior which the authors suspect is probably a result of the sampling design, although it may possibly be caused by a complex of unknown environmental factors. The 100+ hour fuels exhibited a marked tendency to accumulate through time. As fire-killed snags decompose, loadings decrease from a 27 to 32 T/Ha range in early seral stages, to a 9 to 15 ton range at 70 to 100 years since burn. From this point there is a consistent tendency for these heavy fuels to accumulate to 46 T/Ha for stands over 170 years since burn.

TABLE 1. Median fuel loadings[a] and betas by cover type.

	Cover Types								
Fuel types	Glacier N=4	Rock N=4	Talus N=22	Talus-meadow N=5	Meadow N=86	Prairie N=13	Shrub N=22	Krummholz N=49	Upright forest N=218
Litter	.00	.29	.04	.00	.19	.62	1.88	1.28	2.23
Grass &forbs	.00	.28	.11	.05	.76	1.36	.39	.41	.25
1 hour	.00	.00	.00	.05	.01	.07	.50	.48	.80
10 hour	.00	.00	.00	.15	.00	.00	1.13	1.17	1.34
100 hour					.00	.00	1.69	1.71	1.85
100+ hour					.00	.00	9.08	16.14	19.96
Avg. weight shrub foliage					.00	.00	.45	1.71	.42
Avg. weight shrub branchwood					.00	.00	1.62	8.54	1.43
Beta litter		.0094	.0090	.0079	.0078	.0172	.0270	.0233	.0278
Beta downy wood				.0007	.0017	.0017	.0056	.0082	.0101
Beta shrub				.0054	.0011	.0001	.0018	.0033	.0010

[a]Loadings in metric ton/hectare.

TABLE 2. Median fuel loadings[a] by years since burn: 20-year series.

Fuel type	Upper Limits of Years Since Burn Intervals								
	10 N=12	44 N=7	69 N=21	89 N=58	109 N=15	129 N=29	149 N=6	169 N=18	>170 N=48
Litter	.67	2.24	2.00	2.08	2.56	2.74	3.97	2.30	2.15
Grass & forbs	.48	.45	.33	.30	.34	.24	.17	.36	.21
1 hour	.42	1.05	1.06	.72	.88	.96	.86	1.02	1.02
10 hour	2.77	1.18	1.62	1.18	1.24	1.35	1.65	2.19	1.70
100 hour	6.02	3.37	3.38	1.69	3.51	3.43	5.98	1.86	1.70
100+ hour	27.80	32.51	8.93	15.51	9.65	15.00	29.86	29.49	46.71
Shrub foliage	1.13	.74	.40	.41	.42	.44	.31	.44	.20
Shrub branchwood	3.76	5.39	1.35	1.75	1.43	1.60	1.08	1.24	.68

[a]Loadings in metric ton/hectare.

TABLE 3. Median fuel loadings[a] and betas by years since burn 50-year series

Fuel type	Upper Limits of Years Since Burn Interval				
	10 N=12	55 N=26	105 N=75	155 N=50	155+ N=51
Litter	.67	2.18	2.20	2.74	2.15
Grass & forbs	.48	.25	.30	.24	.21
1 hour	.42	1.06	.73	.97	.97
10 hour	2.77	1.34	1.17	1.65	1.62
100 hour	6.02	3.38	1.70	3.37	1.70
100+ hour	27.80	11.97	11.20	21.09	37.02
Shrub filiage	1.13	.72	.38	.39	.19
Shrub beanchwood	3.76	2.24	1.22	1.24	.62
Beta litter		.0238	.0301	.0317	.0255
Beta down woody		.0103	.0083	.0127	.0124
Beta shrub		.0021	.0010	.0009	.0005

[a]Loadings in metric ton/hectare.

Figure 3 illustrates the cumulative probability curves for the three distinct beta strata. At the 80% cumulative probability level, shrub packing ratios were below .0005. The dead and down woody stratum had beta values at .025, while litter was up to .045 at the same 80% level. From Table 3, packing ratios for the three strata reflect the behavior of the loadings of fuels that characterize each particular stratum. Litter beta increased by 20% from its 50 year value and returned to .0255, within 10% of the original value. Packing ratios for the down woody stratum increased by 20% while the shrub backing ratios showed a continuous decrease to 75% of its original value.

Table 4 and Figure 4 summarize the difference in median and total fuel loads for 'mesic and xeric' sites west of the divide in Glacier National Park. Both site types indicate a strong tendency for the total fuel load to accumulate through time. The mesic loadings are from stands that probably did not have *Pinus contorta* as a post burn pioneer species. It is probable that the higher total loads in mesic sites indicate a potential to produce more biomass than xeric sites, rather than assume there is a higher mortality. After a disturbance, sites chosen as xeric generally do not initially support a dominant overstory of *Tsuga heterophylla, Thuja plicata, Picea ssp.*, and *Populus trichocarpa*, but often will regenerate *P. contorta* as a pioneer overstory species immediately following a burn which destroys part of the overstory. Kessell (1977) shows relative abundance of *P. contorta* to be markedly reduced after 100 years since burn for areas west of the divide. As this species becomes more decadent in xeric successional stands, there are increased contributions to all categories of dead fuels from 100 to 150 years since burn. Table 4 shows greater than 100 hour fuel loadings to increase by slightly more than 100% for both wet and dry site types, while associated smaller fuels show a comparable average increase of 98% for the dry sites and only a 14% increase on mesic sites.

Rather than simply analyze a complex set of fuel characteristics and relationships as they interact with each other, it might also be meaningful to consider the total fuel relationships in terms of their effects on fire behavior. A "Fire Hazard and Evaluation System" is being developed by Bradshaw and Bevins at the NFFL in Missoula, MT. The system embodies a procedure for "evaluating and interpreting the fire hazard presented by a fuel complex." It converts raw fuel and weather data into frequency distributions. The information is then submitted to a fire model which integrates them into distributions of fire behavior. If fuel data were categorized into discrete units of increasing years since burn, the effects of post fire succession on hazard may be considered in terms of fire behavior. To obtain estimates of changes in potential fire behavior resulting from fuel accumulation through time, the data were run through a three strata fire model (Bevins, 1976). Fuel moistures used were characteristic of the fifth worst fire danger day at Polebridge in Glacier National Park. Wind speed and temperature were held constant while fuel data were stratified into 50 year intervals along a secondary succession series. Table 5 illustrates the changes in potential rate of spread, scorch height, and fire intensity resulting from fuel accumulation in the park. All three measures of fire behavior

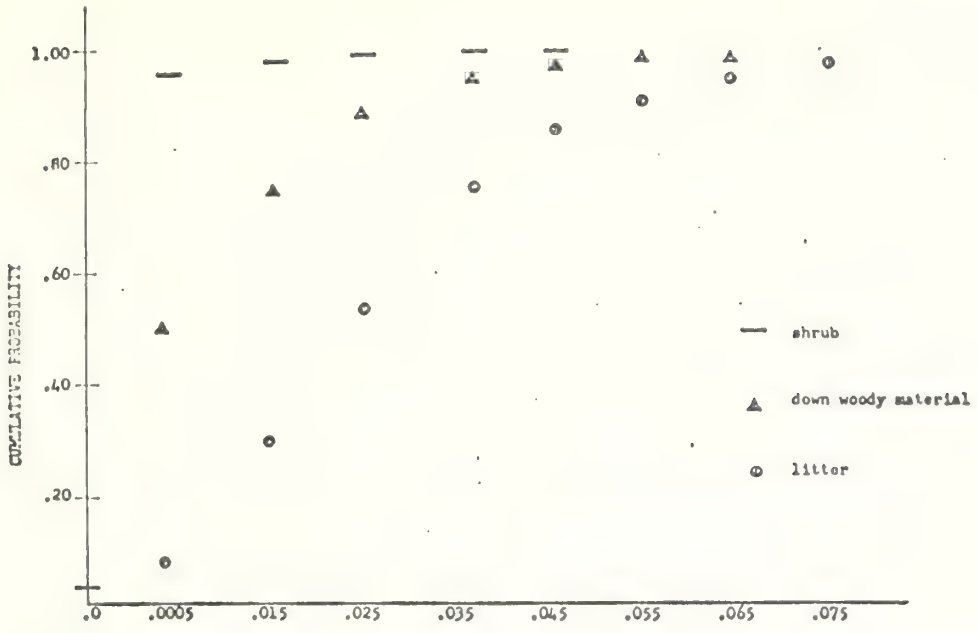

FIGURE 3. Cumulative probabilities for packing ratios of three strata.

TABLE 4. Median loadings[a] betas for wet and dry series by years since burn.

	Upper Limit of Years Since Burn Interval							
	55 N=15		105 N=32		155 N=22		>155 N=11	
Fuel type			Dry	Wet	Dry	Wet	Dry	Wet
Litter	2.18	2.24	2.34	2.05	3.08	2.71	1.97	2.21
Grass & forbs	.33	.14	.34	.29	.40	.22	.22	.21
1 hour	1.06	1.23	.75	.95	.98	.98	1.12	.91
10 hour	1.18	1.69	.59	1.33	1.67	1.59	2.34	1.62
100 hour	3.38	5.11	1.69	1.70	4.34	1.77	1.69	1.87
100+ hour	11.97	15.96	6.75	15.51	14.38	32.24	22.73	53.10
Avg. weight shrub foliage	.74	.48	.39	.39	.38	.43	1.07	.16
Avg. weight shrub branchwood	2.88	1.48	1.16	.138	1.09	1.50	2.62	.36
Beta litter	.0239	.0236	.0314	.0294	.0305	.0317	.0262	.0249
Beta down woody	.0111	.0093	.0060	.0097	.0157	.0124	.0131	.0158
Beta shrub	.0023	.0011	.0009	.0012	.0009	.0008	.0014	.0003

[a]Loadings in metric ton/hectare.

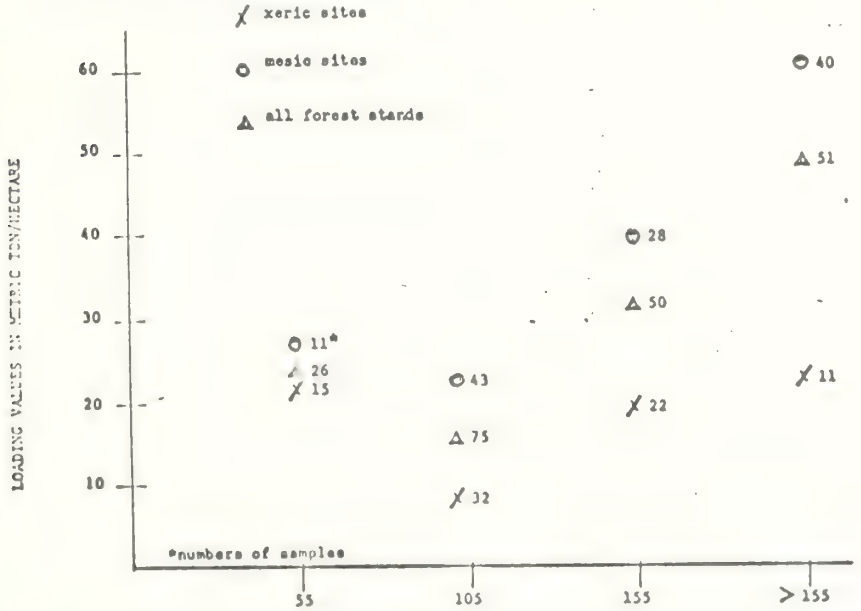

FIGURE 4. Total down woody fuel loadings for sites of differing moisture by years since burn.

TABLE 5. Projected effects on fire behavior by various fuel complexes

TABLE 5. Projected effects on fire behavior by various fuel complexes

	Years Since Burn				Site Type	
	55	105	155	+155	All plots xeric	All plots mesic
Rate of spread meters/min 75% cumulative probability level	36	36	56	54	40	52
Scorch height meters 25% cumulative probability level	14	16	17	20	15	18
Byrams, intensity $KCAL/m^2/sec.$ 25% cumulative probability level	220	260	280	360	240	310

Wind speed = 5.0 mph; temperature = 25°C; fuel moisture: 1 hour = 1%; 10 hour = 2%; 100 hour - 11%; 100 hour = 13%.

showed an increase. The spread rate was 50% faster for stands over 155 years than in young stands, 55 years or less. Byrams intensity increased by 64% affecting a 43% increase in scorch height, from 14 to 20 meters.

CONCLUSION

The authors have illustrated how wildland fuels in Glacier National Park respond to primary succession. The response of forest fuels to post fire secondary succession produces three typical patterns of behavior; fuels which decrease (grasses, herbs, and shrubs,) those which plateau within a characteristic loading range (litter, 1, and 10 hour fuels,) and others which tend to accumulate through time (greater than 100 hour.) The three distinct fuel-vegetation strata have unique packing ratios which change through time relative to the characteristic fuel load values. The fuel complex responds differently on varying types of sites. Also, as fuel characteristics and relationships progress through time, their projected effects change potential fire behavior.

LITERATURE CITED

BEVINS, COLLIN D. 1976. Fire modeling for natural fuel situations in Glacier National Park. presented at First Conf. on Sci. Res. in the Natl Parks. AIBS-USDI NPS conference, Nov 9-13, New Orleans, LA.

BRADSHAW, LARRY, and COLLIN D. BEVINS. 1976. A fire hazard and evaluation system: proposed design and demonstration. Review draft, on file USFS NFFL, Missoula, MT.

BROWN, JAMES K. 1974. Handbook for inventorying downed woody material. USDA For. Serv. Gen. Tech. Rep. INT-16, 24 pp., illus. Intermtn. For. Rang. Exp. Sta. Ogden, Utah.

FOSBERG, MICHAEL A. 1970. Drying rates of heartwood below fiber saturation. Forest Science 16:57-63.

KESSELL, STEPHEN R. 1974. Wildland inventories and fire modeling by gradient analysis in Glacier National Park. Presented at Tall Timbers fire ecology conf. and fire and land managers symposium. Oct. 8-10, 1974, Missoula, MT.

KESSELL, STEPHEN R. 1977. A gradient vegetation, resource and fire management model for Glacier National Park. Unpublished doctoral thesis, Section Ecology and Systematics, Cornell Univ. Ithaca, NY.

ROTHERMEL, RICHARD C. 1972. A mathematical model for predicting fire spread in wildland fuels. USDA For. Serv. Res. Pap. INT-115, 40 pp., illus. Intermtn. For. Rang. EXP. Sta., Ogden, Utah.

FIRE MODELING FOR NATURAL FUEL SITUATIONS IN GLACIER NATIONAL PARK

Collin D. Bevins[1]

INTRODUCTION

A mathematical fire spread and intensity model has been developed by the USDA Forest Service at the Northern Forest Fire Laboratory, Missoula, Montana (Rothermel 1972). The model predicts potential fire behavior based upon empirical relationships with easily measured site, weather, and preburn fuel factors. The fire model has been widely used, from providing relative fire danger indices (Deeming et al. 1972), to attempting real time fire behavior estimation in wildland fuels (Kessell 1977). However, certain assumptions inherent in the development of the model have limited its application to real world fuel situations. In most instances, it is not the fire model or its assumptions per se that are limiting, but rather the manner in which the environmental-fuel complex is simulated as to conform to those assumptions. This paper outlines several adaptations in the use of the fire model and the simulation of the fuel arrays which, without altering the model's equations or assumptions, can make it more applicable to variable, natural fuels.

REVIEW OF THE ROTHERMEL FIRE MODEL

A theoretical basis for the model was provided by Frandsen (1971) through application of the conservation of energy law. He considered two identical, horizontally contiguous unit volumes of a fuel array. The two unit volumes are the smallest possible that retain the same characteristics as the larger complex of which they are a part. If one volume is totally ignited, the spread rate R from the first to the second is proportional to the ratio of the heat source offered by the ignited volume to the heat sink of the unburned volume:

$$R \propto \text{Heat source} / \text{Heat sink} .$$

The research and development of the Rothermel fire model proceeds from this theoretical foundation, predicting spread rate as a function of the ratio of the heat source to the heat sink.

The model's empirical relationships were established by burning fuel beds of known characteristics under laboratory controlled moisture, wind, and slope conditions. The fuel beds were constructed of uniformly sized, homogeneous particles (0.066 cm square excelsior, 0.635 cm square sticks, or 1.270 cm square sticks) arranged in a continuous array.

The fire model predicts the rate of spread R (m/s) by

$$R = \frac{I_R \cdot \xi}{\rho_b \cdot \varepsilon \cdot Q_{ig}} \cdot (1 + \phi_w + \phi_s) . \qquad (1)$$

The heat source term (numerator) contains the reaction intensity I_R (kcal/m^2-s) and the propagating heat flux ratio ξ (fraction). ξ is the proportion of the I_R available for the propagation of the fire front. Their product is the no-wind, no-slope propatating heat flux (kcal/m^2-s).

The heat sink term (denominator) contains the heat required to bring a unit mass of fuel to the ignition point Q_{ig} (kcal/kg fuel) and the fuel bed's bulk density ρ_b (kg fuel/m^3 fuel bed). The product of the two terms is the volumetric heat requirement of the fuel bed. The effective heating number ε (fraction) is the proportion of the fuel mass that must be brought to ignition to sustain pyrolysis. The denominator of Equation 1 thus represents the heat required to raise a critical volume of fuel to ignition to maintain a propagating fire front (kcal/m^3).

The terms discussed provide an estimate of the spread rate for the no-wind, no-slope case (R_o). The combined effects of slope and wind on fire is treated as a dimensionless multiplication factor ($1 + \phi_w + \phi_s$) by the model, where ϕ_w and ϕ_s are the wind and slope effects, respectively.

With the important physical factors determining fire spread defined, the experimental fuel beds were ignited to relate the terms of Equation 1 to more easily measured fuel and environmental properties. The series of burnings were designed to (1) relate rate of spread to reaction intensity via the dynamic heat flux factor ξ, (2) relate reaction intensity to the reaction velocity Γ', a dimensional parameter, (3) determine the dependence of reaction velocity upon measurable fuel properties such as load and porosity, and (4) relate wind and slope effects on fire spread to the environment and arrangment of the fuel array.

By observing the spread rate and estimating the reaction intensity of experimental fires in fuel beds of known characteristics, the propagating heat flux ratio ξ could be computed from a rearrangement of Equation 1 :

$$\xi = \frac{R \, Q_{ig} \, \rho_b \, \varepsilon}{I_R} .$$

The value of ξ was then related to static fuel array properties, and found to be a function of the surface-area-to-volume ratio σ (1/m) and the packing ratio β (m^3 fuel/m^3 fuel bed). The tilde operator ($\tilde{}$) indicates that the value used is a weighted average for all fuel types present in the array. The packing ratio is determined from the fuel bed depth δ (m) and the fuel particle density ρ_p (kg fuel/m^3 fuel):

$$\beta = \frac{\rho_b}{\rho_p} = \frac{\omega_o}{\delta \, \rho_p}$$

where ω_o is the total ovendry fuel load (kg ovendry wood/m^2).

The reaction intensity I_R was related to the reaction velocity Γ' (s^{-1}) by

$$I_R = \Gamma' \, h \, \omega_n$$

where h is the low heat of combustion of the fuel (kcal/kg) and ω_n is the net fuel load (kg/m^2). The net fuel load ω_n is derived from the total fuel load ω_o by

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$$\omega_n = \omega_o (1 - S_T)$$

where S_T is the total mineral content of the fuel (kg minerals/kg ovendry wood).

The reaction velocity was found to be a complex function of the surface-area-to-volume ratio σ and packing ratio β of the array for pure, dry cellulosic fuels. When the fuel is not dry or has non-silica minerals in it, the Γ' is reduced. Two damping coefficients therefore modify the optimum reaction velocity. The mineral damping coefficient η_s (dimensionless) is a function of the fuel particle silica-free mineral content S_e (kg non-silica minerals/kg ovendry wood). The moisture damping coefficient η_m (dimensionless) is a function of the ratio of the fuel particle moisture content M_f (kg moisture/kg ovendry fuel) to the moisture content of extinction M_x (kg moisture at which fire spread drops to zero/kg ovendry fuel). The values of η_s and η_m may range between 0.0 and 1.0. The final form of the reaction intensity equation is then

$$I_R = h\, \omega_n\, \Gamma'\, \eta_s\, \eta_m .$$

In the heat sink term of Equation 1, the heat of preignition is a function of the fuel particle moisture content M_f. The effective heating number ε was determined by placing small thermocouples within individual fuel particles and measuring the penetration depth of the ignition temperature in the preheating phase (Frandsen 1973). The porportion of the fuel mass reaching ignition in the preheating phase was related to the particles' surface-area-to-volume ratios.

The effects of wind and slope on fire spread were found to be functions of the fuel's environment and arrangement :

$$\phi_w = f(U, \beta, \sigma)$$

$$\phi_s = f(S, \beta)$$

where U is the windspeed at midflame height (m/s) and S is the terrain slope (degrees).

With all the factors in Equation 1 defined as functions of measurable fuel characteristics and environmental conditions, it becomes possible to predict potential fire behavior from the set of parameters listed below. The subscript i denotes the fuel category (live or dead) and j denotes the fuel size class (fuel particle diameter stratification).

(1) $(h)_{ij}$: fuel particle low heat of combustion (kcal/kg fuel)

(2) $(\rho_p)_{ij}$: fuel particle density (kg fuel/m^3 fuel)

(3) $(S_T)_{ij}$: fuel particle total mineral content (kg minerals/kg ovendry wood)

(4) $(S_e)_{ij}$: fuel particle non-silica mineral content (kg non-silica minerals/ kg ovendry wood)

(5) $(\sigma)_{ij}$: fuel particle surface-area-to-volume ratio (m^{-1})

(6) $(M_f)_{ij}$: fuel particle moisture content (kg moisture/kg ovendry wood)

(7) $(\omega_o)_{ij}$: total fuel load (kg ovendry wood/ m^2)

(8) δ : fuel bed depth (m)

(9) M_x : fuel moisture content of extinction (kg moisture/kg ovendry wood)

(10) U : windspeed at midflame height (m/s)

(11) S : terrain slope (degrees)

In modeling fuel arrays, it is often convenient to consider the first four parameters (h, ρ_p, S_T, and S_e) as constants due to their low natural variability or the model's low sensitivity to them. The moisture content of extinction M_x, while probably a function of the fuel's packing ratio and ambient windspeed, is also currently treated as a constant due to a lack of quantitative data. The fuel moisture content M_f, slope S, and windspeed U are time or space specific. The surface-area-to-volume ratio σ may be considered constant within each fuel species' size class j (Brown 1970a, Brown and Roussopoulos 1974). This leaves the fuel load ω_o and bed depth δ as the two parameters distinguishing one fuel array from another.

The model is most sensitive to the windspeed parameter U; a change in U generally affects a proportional or greater than proportional change in the spread rate R. The model is also highly sensitive to the surface-area-to-volume ratio σ and packing ratio β, as these parameters appear repeatedly in the intermediate equations.

Some changes have been recently made to the original 1972 version of the Rothermel model by Albini (1976). These changes are concerned mainly with adjustments in some of the curve fitting equations, moisture content of extinction determination for live fuels, and the burning properties of live fuels. For a more thorough discussion of the model's design, development, equations, and parameters, the reader is referred to Rothermel (1972) and Albini (1976).

Because the model's equations were developed by burning fuel beds of uniformly sized particles, it accepts only a single value for each of the eleven input parameters. For application to heterogeneous fuel complexes, there exists the modeling problem of characterizing a wide distribution of parameter values with a single number. First, the distribution of the fuel characteristics within the array must be described. Then, a weighting system is needed to reduce the fuels description to representative input values.

Fuels are classified into discrete fuel moisture time lag classes of 1, 10, 100, and >100 hour fuels. Time lag is the time required for a nonliving material to gain or lose 1 - 1/e of its moisture content with respect to an equilibrium moisture content (Fosberg 1970). More simply, it is the time required for a fuel particle to respond to a change in the ambient humidity. The time lag classes generally correspond to fuel particle diameter size classes of <0.64, 0.65 to 2.54, 2.55 to 7.62, and >7.62 centimeters, respectively. For use in the fire model, fuel particles are identified by live vs. dead category and by the time lag size class to which it belongs.

A weighting system is required to mathematically reduce the parameter values for each fuel category i and size class j of a heterogeneous fuel array into a single model input (denoted by the tilde operator ~). For rate of spread estimates, Rothermel (1972) proposes a surface area weighting method where the input value for each size class is weighted by that classes' proportional contribution to the total surface area of the fuel array. This procedure is based upon the assumption that fire spread is largely dominated by the smaller fuels with higher surface-area-to-volume ratios. The weighting factor f_{ij} for each

category and size class is calculated by

$$f_{ij} = A_{ij} / A_T$$

$$A_{ij} = \sigma_{ij} \, (\omega_o)_{ij} / (\rho_p)_{ij}$$

$$A_T = \sum_{i=1}^{i} \sum_{j=1}^{4} A_{ij}$$

where A_{ij} is the surface area of fuel ij and A_T is the total surface area of the fuel area (m^2 surface area/m^2 ground area).

The surface area weighting system has not been developed or tested in fuel beds under laboratory conditions, but appears to perform well in field tests. Brown (1972) tested the model in slash fuel plots carefully constructed to approximate a continuous fuel array. Bevins (1975) tested the model's accuracy in on-site activity fuels on the Olympic Peninsula, also in plots selected for their apparent continuity of fuels. Sneeuwjagt conducted tests of the model in grass and range plots similarly selected for their continuous fuels (Sneeuwjagt 1974, Sneeuwjagt and Frandsen, in press). These three studies found the fire model to consistently predict spread rates within a factor of 0.5 to 2.0 of the observed spread rate. This prediction accuracy is especially encouraging considering the natural variability within the burned fuel arrays, the sampling error in the estimation of mean parameter values for each fuel category and size class, and the untested effects of the surface area weighting method. However, it appears possible to make the model more accurate in its application to natural, discontinuous fuels by altering the manner in which it is used and by refining the mathematical simulation of the fuel complexes to be burned.

FIRE MODEL LIMITATIONS

Two limitations in the model's design and development are evident in its application to wildland fuels. First, it assumes that the fuel array is continuous in all its characteristics in the horizontal and vertical planes. That is, the array must consist of a matrix of identical, contiguous unit volumes such that for any fuel parameter p, $d_p/dx = d_p/dy = d_p/dz = 0$. Second, the model predicts fire spread and intensity in the up-wind, up-slope direction only.

The first limitation, that of fuel continuity, may be used to advantage in simulating the natural variability of the fuel complex. This becomes possible when spatial fuel parameter distributions rather than mean or average values are used to define the fuel bed to be burned. This includes the description of how the fuel complex changes in its vertical profile and in its pattern across the forest floor.

The second limitation is a consequence of the methods used in the model's development. The effects of wind and slope were measured by burning long, narrow, tilted fuel beds within a low-speed wind tunnel. It was not possible under these conditions to test for the effects of cross-slope winds on fire spread. As a result, the model's use as a predictor for fire perimeter growth and fire behavior around the perimeter is restricted. The restriction may be overcome for modeling purposes by examining the interactions of the vector components of wind and slope factors for cross-slope wind cases.

VERTICAL CONTINUITY: THE STRATA CONCEPT

The assumption of vertical continuity is difficult to accept in any real world application of the Rothermel model. Studies by Brown (1970b) and Bevins (1975) have shown slash fuels to have a nonlinear vertical packing ratio profile. The packing ratio is highest at the bottom of the fuel bed, and decreases to zero as it approaches the top. Jeske and Bevins (1976) discuss the tendency of natural ground fuels in Glacier National Park to fall into three discrete vertical strata. Each stratum has a distinct packing ratio, surface-area-to-volume ratio, and moisture content of extinction. The three fuel-vegetation strata defined are (1) the compacted litter and duff layer above the mineral soil, (2) the non-woody herbs and grasses, and fallen branchwood above the litter, and (3) the supported, woody-stemmed shrubs. Individually, each stratum approximates the assumption of vertical fuel continuity and homogeneity more closely than when the bed is considered as a whole.

The recognition of three discrete fuel-vegetation strata in natural ground fuels led to the strata fire model adaptation of the Rothermel model. This approach evaluates fire behavior, using the Rothermel model, for each fuel-vegetation stratum independent of the other two. Two assumptions are made in this adaptation: (1) the fire will spread first and fastest through the most flammable fuel stratum, independent of the other two strata, and (2) this "optimum stratum" will serve as an ignition source for the other two strata after some small time delay. These assumptions allow an estimation of maximum fire spread R_{max} based upon a single stratum's fuel array and burning properties. These burning properties include the stratum's reaction intensity I_R (kcal/m^2-s), spread rate R (m/s), and fire residence time τ_r (s).

An important burning characteristic is the fireline intensity I_F (kcal/m-s), or the heat flux produced per unit depth of the combustion zone. It can be estimated for each stratum by

$$(I_F)_i = R_i \, (I_R)_i \, (\tau_r)_i$$

where i denotes the stratum (1 = litter, 2 = herbs, grasses, and fallen branchwood, 3 = shrubs). The rate of spread R_i (m/s) and reaction intensity I_{Ri} (kcal/m^2-s) are available from the fire model equations for each stratum. The fire residence time τ_r (s) was found by Anderson (1969) to be related to the fuel particle surface-area-to-volume ratio σ. For the i^{th} stratum,

$$(\tau_r)_i = c / \sigma_i$$

where c is a constant.

Under the assumption that the fire spreads first and fastest through a single optimum stratum, the flame length ℓ (m) at the leading edge of the combustion zone can be estimated from the optimum stratum's fireline intensity. Using Byram's (1959) flame length equation,

$$\ell = a \, (I_F)^b$$

$$= a \, \{ R_{max} \, (I_R)_i \, c/\sigma_i \}^b$$

where a, b, and c are constants and i indicates the optimum stratum.

Once the fire has passed through and ignited the optimum stratum, it is assumed to serve as an ignition source for the other two strata. The mechanisms of ignition may include upward heat

through the fire plume or burning embers falling to the ground. When all three strata are burning simultaneously, the total fireline intensity $(I_F)_T$ is dependent upon the total fireline depth (as determined by R_{max}) and the sum of the products of the stratum reaction intensities and residence times :

$$(I_F)_T = R_{max} \sum_{i=1}^{3} \{ (I_R)_i (t_r)_i \}.$$

Total fireline intensity would be appropriate for estimating flame length when all three strata are burning simultaneously, and for calculating crown scorch or crown ignition temperature heights (Van Wagner 1973).

The strata model accepts a packing ratio parameter β_i for each stratum rather than three bed depth values. The packing ratio is calculated by

$$\beta_i = \frac{1}{\delta_i} \sum_{i=1}^{4} \{ (\omega_o)_{ij} / (\rho_p)_{ij} \}$$

where j indicates the fuel particle size class within stratum i. Also, total grass and herb, and shrub loads are split into dead and live categories in the strata model by the use of a percent cured parameter $(P_d)_i$ for strata 2 and 3.

By splitting the fuel complex into three autonomous arrays, there is a tendency within each stratum to have a smaller variety of fuel components than for the entire array. This is particularly true for the litter layer which consists primarily of one hour time lag fuels. Reduction in the variety of fuel particle types tends to reduce the unknown effects of weighting diverse parameter values to derive one characteristic input.

HORIZONTAL CONTINUITY

Approaches to simulating fuel arrays have been proposed that meet the fire model's assumption of horizontal fuel continuity and account for the natural variability of fuel characteristics (Kourtz and O'Regan 1971, Frandsen 1974). The fuel array is divided into a network of contiguous cells forming either a square or hexagonal gridwork. The fuel array is assumed to be continuous in its characteristics in all three dimensions within a cell, but may vary between cells. By sampling the population of fuel array characteristics to be simulated, it is possible to stochastically reconstruct an artificial matrix that duplicates the natural variability of the fuel bed properties in the real world. The fire model is then used to simulate a fire spreading through each of the cells and between the cells. Using the fire model's equations, Frandsen (1974) determined the 'delay time' for the fire to escape from one burning cell into an adjacent unburned cell. By igniting a 'bottom' strip of cells and simulating fire spread through the perpendicular cell rows in the up-wind, up-slope direction, he derives a distribution of fire delay times and spread rates through each row about which confidence intervals can be placed.

Such an approach would prove especially valuable if it were possible to deterministically model or map each cell of the fuel array being simulated, or to derive mathematical -serial relationships of how fuel array characteristics change through space for a given fuel type. Since neither of these techniques is currently feasible, the strata model uses a simple algorithm to account for horizontal fuel discontinuities. A new input parameter is introduced, the percent of ground area covered by each stratum $(P_s)_i$. A weighted optimum spread rate is calculated by allowing the fire to spread through the fastest stratum present for a distance equal to its percent cover. Where the optimum stratum is absent, it spreads through the next fastest stratum. Where both of these two strata are absent, the fire will necessarily pass through the third. The algorithm assumes that for any random transect (or fire spread vector) through the fuel array, the fire will intercept each stratum for a proportion of its length equal to that stratum's P_s value. This appears to be a viable assumption if the fire is allowed to spread along any vector for a great enough distance. The algorithm also assumes a pyramidal stacking of fuel strata where $(P_s)_3 \leq (P_s)_2 \leq (P_s)_1$. The shrub stratum always has herbs, grasses, or fallen branchwood below it. Similarly, the herbs, grasses, and fallen branchwood will tend to have a litter layer beneath it.

FIRE PERIMETER GROWTH: WIND AND SLOPE VECTORS

It is possible to obtain estimates of fire spread for cross-slope winds by evaluating the wind and slope vectors at selected compass angles. The vectors of the two influences can be computed once the wind direction and terrain aspect are known :

$$U_v = U \{ \cos(V-U_d) \},$$

where U_V is the effective windspeed at midflame height (m/s) in the compass angle vector V, and U_d is the wind direction. Similarly for slope :

$$S_v = S \{ \cos(V-S_d) \},$$

where S_V is the effective slope along the vector of interest V, and S_d is the aspect of the terrain.

To find the rate of spread in any vector V under the combined influence of an ambient windspeed at midflame height of U and terrain slope S :

$$R_v = R_o (1 + \phi_w + \phi_s)_v$$

where R_V is the spread in vector V and R_o is the no-wind, no-slope spread rate. The multiplication factor $(1 + \phi_w + \phi_s)_v$ is determined using the U_V and S_V values for vector V.

Using the cosine function, ϕ_w or ϕ_s may take on positive or negative values independent of each other. The two factors may interact, for example, when simulating a down-slope wind: the wind influence is positive and the slope influence negative for the down-slope spread vectors, and vice versa for the up-slope spread vectors. Beaufait (1965) examined the backing rates of pine needle litter fires into the wind within a wind tunnel. For winds of 1.5 to 8.0 miles per hour, he found the backing rate to be nearly the same as the no-wind spread rate. The combined wind-slope multiplication factor is therefore maintained above a lower limit of 1.0.

The vector analysis of wind and slope has several advantages. First, a fire perimeter is projected that forms an ellipse if fuel and terrain factors are horizontally constant. Second, since ϕ_w and ϕ_s are dependent upon fuel array properties, it is possible for the optimum spread stratum in one vector to be different from the optimum spread stratum in another vector. Therefore, a fire may be simulated that heads through the shrubs stratum, flanks through the grasses and dead and down fuels, and backs through the litter layer. With an elliptical

fire perimeter expanding at different rates and through different strata about its perimeter, estimates of fire behavior may be projected at selected points. These projections may include spread rate (perimeter growth rate), stratum of fastest spread, fireline intensity, flame length, and crown scorch and crown ignition temperature heights.

Another possible benefit of the vector analysis stems from the different effects of various windspeed vectors on fire behavior in three strata with unique burning characteristics. By modeling shrubby or brushy fuels and simulating fire spread in them with the three strata model, 'blow up' fire weather and hazard conditions could be defined where the leading edge of the combustion zone jumps from the lower strata and spreads through the shrubby fuels layer.

SUMMARY

The design and development of the Rothermel (1972) fire model has been reviewed with respect to its limitations in application to wildland fuels. The limitations are not necessarily due to the model or its assumptions per se, but rather to the manner in which fuel arrays are simulated. The two major limitations are:

(1) the model assumes a vertically and horizontally continuous, uniform, and homogeneous fuel array, and

(2) the model predicts fire behavior in the upslope, up-wind direction only.

The model's assumption of vertical continuity is approached when the fuel-vegetation complex is simulated as three discrete vertical strata. Each stratum has unique fuel array and burning characteristics, and is evaluated individually for its potential spread rate, reaction intensity, residence time, and fireline intensity. To obtain crown scorch and crown ignition temperature heights, the total fireline intensity from the three strata is used.

The horizontal discontinuity of the fuel is treated simply by applying a percent cover estimate for each stratum. The percent ground cover is then used to compute a weighted spread rate for any direction of fire travel.

The second limitation may be overcome for modeling purposes by breaking wind and slope effects on spread rate into their vectoral components and evaluating fire perimeter growth and behavior along selected fire spread vectors.

The strata fire model adaptation of the Rothermel model estimates fire behavior around an expanding, ellipsoid perimeter. While the approach has not been tested in on-going fire situations, it has performed very well in tests on historical fires in Glacier National Park. Its use requires a modified version of Brown's (1974) technique for assessing fallen woody fuels to obtain the additional input parameters of litter and shrub fuel loads, percent cured, and percent ground cover. The field technique is simple and straightforward, and provides the inputs necessary to more faithfully model natural fuel complexes and simulate fire behavior using the strata fire model adaptation.

LITERATURE CITED

ALBINI, F. A. 1976. Computer-based models of wildland fire behavior: a users' manual. USDA For. Serv. Gen. Tech. Rep. Intermountain For. and Range Exp. Sta., Ogden, UT. 68 p. illus.

ANDERSON, H. E. 1969. Heat transfer and spread. USDA For. Serv. Res. Pap. INT-69. 20 p.

BEAUFAIT, W. R. 1965. Characteristics of backfires and headfires in a pine needle fuel bed. USDA For. Serv. Res. Note INT-39. 7 p. illus.

BEVINS, C. D. 1975. An evaluation of the slash fuel model of the 1972 National Fire Danger Rating System. Masters thesis, College For. Res., U. of Washington, Seattle, WA. unpublished. 104 p. illus.

BROWN, J. K. 1970a. Ratio of surface area to volume for common fine fuels. Forest Science 16:101-105.

BROWN, J. K. 1970b. Vertical distribution of fuel in spruce-fir logging slash. USDA For. Serv. Res. Pap. INT-81. Intermtn. For. Range Expt. Sta., Ogden, UT. 9 p. illus.

BROWN, J. K. 1972. Field test of a rate-of-spread model in slash fuels. USDA For. Serv. Res. Pap. INT-116. Intermtn. For. Range Expt. Sta., Ogden, UT. 24 p. illus.

BROWN, J. K. 1974. Handbook for inventorying downed woody material. USDA For. Serv. Gen. Tech. Rep. INT-16. Intermtn. For. Range Expt. Sta., Ogden, UT. 24 p. illus.

BROWN, J. K., and P. J. ROUSSOPOULOS. 1974. Eliminating biases in the planar intersect method of estimating volumes of small fuels. Forest Science 20·350-356.

BYRAM, G. M. 1959. Combustion of forest fuels. *In* Forest Fire: Control and Use. Chap. 3. K. P. Davis, ed. McGraw Hill, New York. 584 p. illus.

DEEMING, J. E., J. W. LANCASTER, M. A. FOSBERG, R. W. FURMAN, and M. J. SCHROEDER. 1972. National fire danger rating system. USDA For. Serv. Res. Pap. RM-84. Rocky Mtn. For. Range Exp. Sta., Fort Collins, CO. 165 p. illus.

FOSBERG, M. A. 1970. Drying rates of heartwood below fiber saturation. Forest Science 16:57-63.

FRANDSEN, W. H. 1971. Fire spread through porous fuels from the conservation of energy. Combustion and Flame 16:9-16.

FRANDSEN, W. H. 1973. Effective heating of fuel ahead of spreading fire. USDA For. Serv. Res. Pap. INT-140. Intermtn. For. Range Exp. Sta., Ogden, UT. 16 p. illus.

FRANDSEN, W. H. 1974. A fire spread model for spatially nonuniform forest floor fuel arrays. Presented at Western States Section, The Combustion Institute, Northridge, CA. Oct. 21-22, 1974. 36 p. illus.

JESKE, B. W., and C. D. BEVINS. 1976. Spatial and temporal distributions of natural fuels in Glacier Park. Presented at the First Conference on Scientific Research in the National Parks, AIBS-USDI NPS conference, Nov. 9-13, 1976. New Orleans, LA. 20 p. illus.

KESSELL, S. R. 1977. Gradient modeling: a new approach to fire modeling and resource management. *In* Models as Ecological Tools - Theory and Case Histories. Hall and Day, eds. Wiley and Sons, New York. in press.

KOURTZ, P. H., and W. G. O'REGAN. 1971. Model for a small forest fire...to simulate burned and burning areas for use in a detection model. Forest Science 17:163-169.

ROTHERMEL, R. C. 1972. A mathematical model for predicting fire spread in wildland fuels. USDA For. Serv. Res. Pap. INT-115. Intermtn. For. Range Exp. Sta., Ogden, UT. 40 p. illus.

SNEEUWJAGT, R. J. 1974. Evaluation of the grass fuel model of the National Fire Danger Rating System. Masters thesis, College Forest Resources, U. of Washington, Seattle, WA. 162 p. illus. unpublished.

SNEEUWJAGT, R. J., and W. H. FRANDSEN. 1977. Behavior of experimental grass fires vs. prediction based on Rothermel's fire model. in press for Canadian Journal of Forest Research.

VAN WAGNER, C. E. 1973. Height of crown scorch in forest fires. Canadian Journal of Forest Research 3:373-378.

THE FIRE MANAGEMENT PLAN FOR PINNACLES NATIONAL MONUMENT

James K. Agee[1] and Harold H. Biswell[2]

INTRODUCTION

Pinnacles National Monument is a 14,500-acre natural area located in the central coast range of California (Figure 1). Established primarily to preserve volcanic outcroppings for which it was named, Pinnacles contains almost 12,000 acres of chaparral vegetation. Although the monument does not encompass the entire range of chaparral conditions (USDI 1972), it is the National Park System's only example of a natural coast range chaparral community. Fire management is to play an important role in natural resources management at Pinnacles National Monument.

Fire has always been an integral part of California's chaparral (Agee 1974). Chaparral communities have burned so often in the past and yet recover so quickly that they are regarded as fire-adapted types. Most chaparral plants have one or more of the following fire adaptations: stump-sprouting after fire, producing adundant seed at an early age, and possessing seed that will lie dormant and viable in the soil until a fire passes by (Jepson 1921; Biswell 1974). In the distant past, lightning was a primary source of fire ignition. Those fires may have been ignited in the chaparral itself, or in other vegetation and carried into the monument's chaparral through the dry summer months. Those natural fires has little effect on the chaparral except to reduce fuels and create mosiacs of different age classes (Biswell 1974). The reduced fuel and different age classes served as barriers to fire spread and helped prevent intense and larger fires at some later date (Philpot 1973).

In addition to the lightning fires, Indians also may have burned chaparral in early summer or late fall for several reasons: to improve access and travel through the chaparral, to reduce the intensity of summer fires that might occur during extreme fire weather, to improve conditions for wildlife and hunting, and to preserve the oak trees in the foothill woodland-grass areas for their acorns. There is also a high probability that accidental or incendiary fires occurred too.

Pinnacles National Monument was established as a forest reserve in 1906 and became a national monument 2 years later. A loosely applied fire suppression policy was the fire management strategy for several years. As funding and organization of fire control forces improved over the years, the policy of quick fire suppression became more effective. The California Division of Forestry, along with the National Park Service, continued the fire suppression policy with high success for many years because fuels were light and broken into mosaics of age classes by frequent fires of the past, and fire fighting techniques became more sophisticated. However, the fire suppression job became more difficult over the years as the age class mosaics blended into widespread, uniform, heavy fuels.

At the same time that wildfires were beginning to become increasingly uncontrollable, the National Park Service was becoming aware of the role that fire played in maintaining natural ecosystems. In 1968 the National Park Service adopted a new and more realistic policy concerning the preservation of the vegetation and wildlife in its parks. Pertinent excerpts from this new policy, revised in 1975, are:

1. The presence or absence of natural fires within a given ecosystem is recognized as a potent factor stimulating, retarding or eliminating various components of that ecosystem.

2. Natural fire is the preferred means to achieve the prescriptions of natural zones.

3. In ecosystems modified by prolonged exclusion of fire, prescribed burning may be used to reduce fuel loading to natural levels, or to reduce fuels along boundaries of management zones and thereby reduce the probability of wildfires crossing into or out of the zone.

4. Prescribed burning may be used as a substitute for natural fire in the prescription for natural zones where it is determined that natural fires cannot meet the objectives.

5. Clearly defined limits will be established in the prescription of all management fires, beyond which limited or complete control action will be undertaken.

Restoration of fire to the Pinnacles environment is predicated on National Park Service policy and management objectives that have been thoroughly reviewed by the public through the master plan (USDI 1975) and the natural resources management plan (USDI 1975). A fire management plan has been developed within these objectives and within constraints present at the Pinnacles.

THE PINNACLES ENVIRONMENT

The Pinnacles environment is a classic fire environment. Weather, topography, and fuels combine to produce an extremely fire susceptible community, one that probably burned every 15 to 30 years under natural conditions. The climate is a Mediterranean type, with cool, moist winters and dry, hot summers. Average rainfall is 40 cm (16 inches), most of which falls between November and March. Summer temperatures often exceed 39 degrees C (100 degrees F).

Topography at the Pinnacles can be described as steep and rugged, with many ridges, peaks, and deep canyons. The elevation increases from about 300 m (1000 ft) where Chalone Creek leaves the monument at the last entrance up to 1000 m (3304 ft) at North Chalone Park.

The soils to be found within the Pinnacles National Monument embody no unusual features. Throughout they are sandy loams or loamy sands, often containing an appreciable amount of gravel, typically thin and undeveloped, with a low ability to retain nutrients and water. Nutrient supply is moderately low but nutrient components are well balanced (Soil Survey, San Benito County, California 1969). Erosion hazards are high.

Plant cover (Figure 2 consists of about 80%

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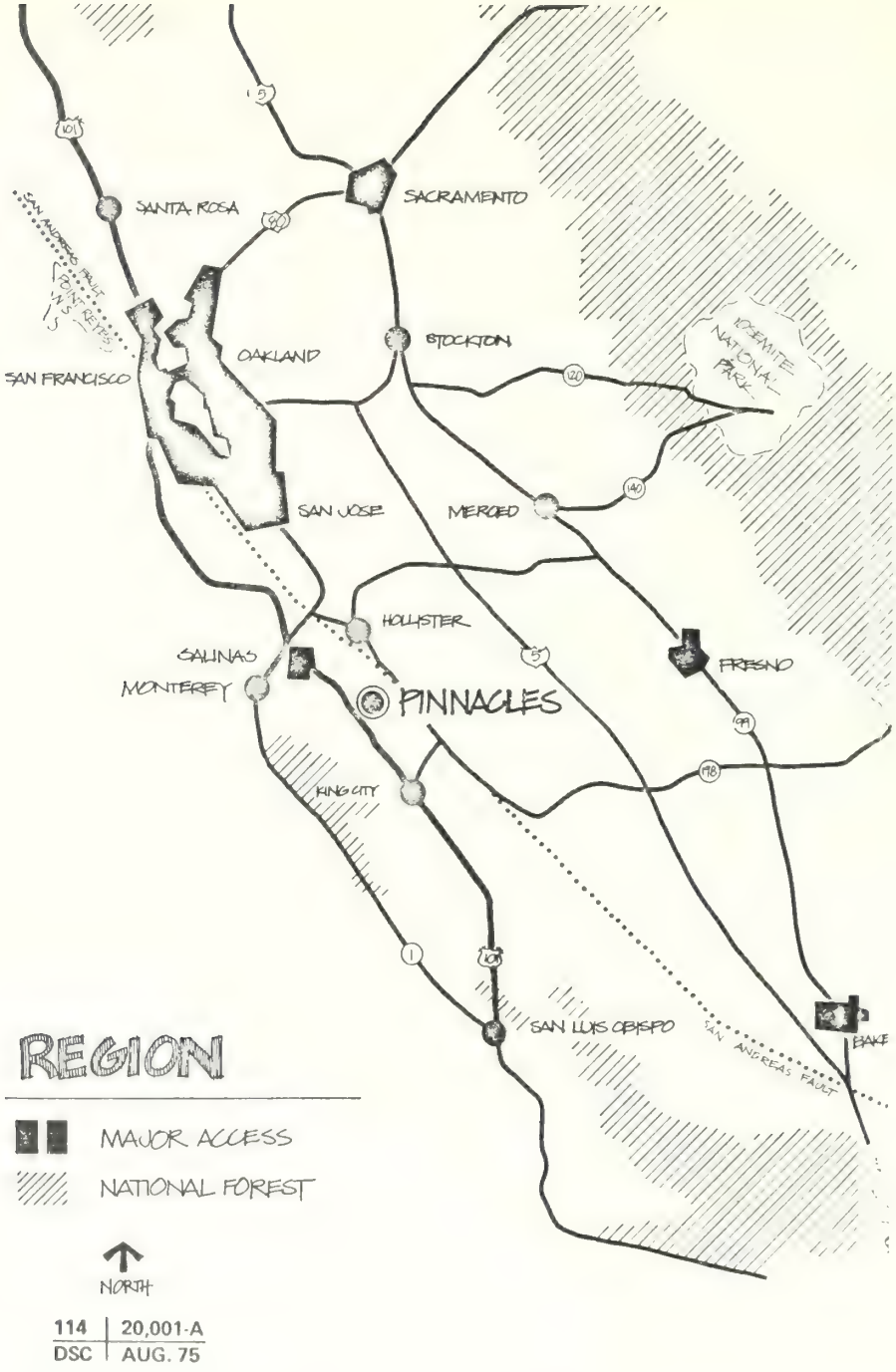

FIGURE 1. Pinnacles National Monument is about 150 miles south of San Francisco.

FIGURE 2. Chaparral is the primary vegetative cover at Pinnacles National Monument. Photo by Nick Weeks.

FIGURE 3. Digger pines (*Pinus sabiniana*) are interspersed throughout the chaparral. Photo by Nick Weeks.

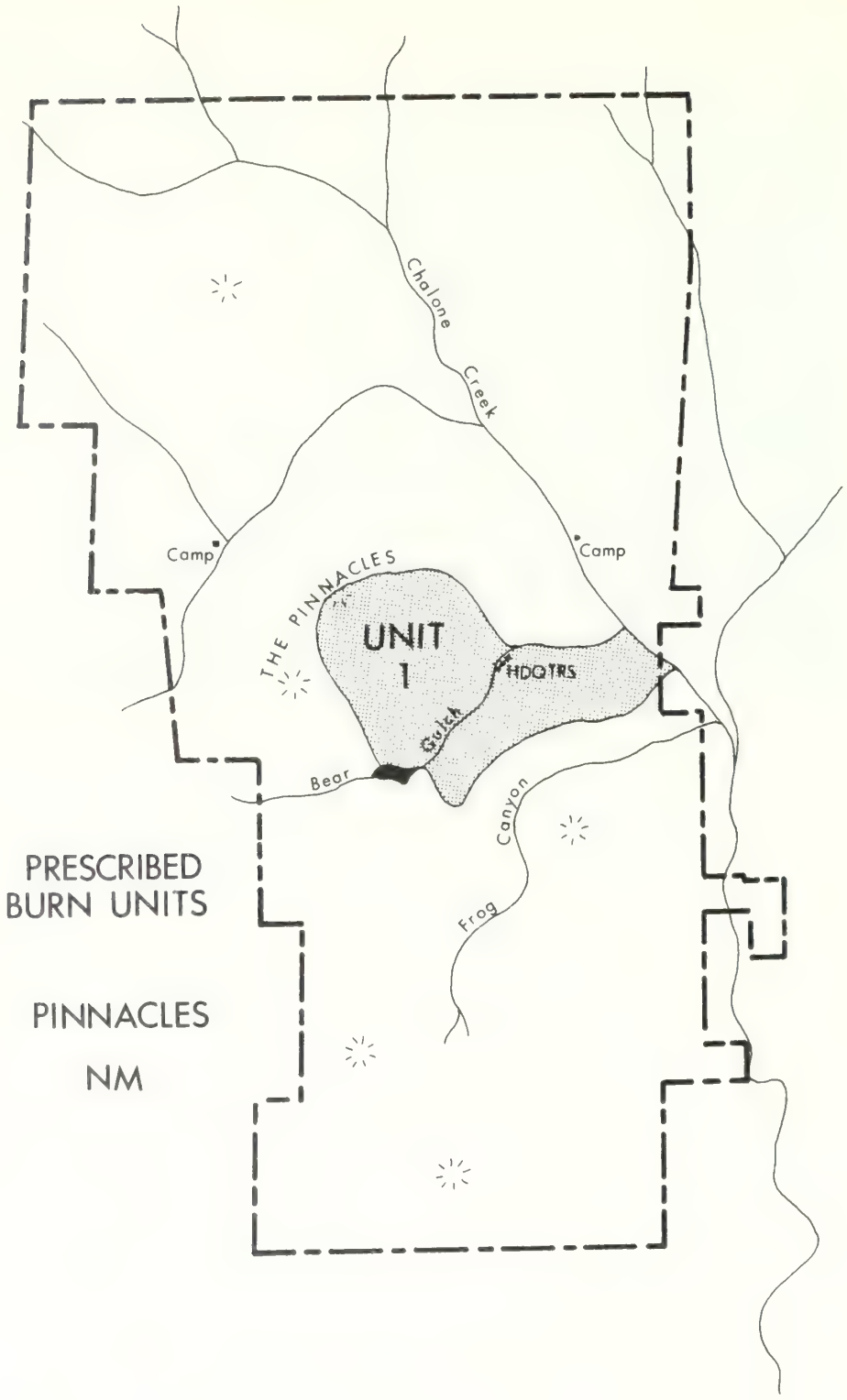

FIGURE 4. Burning in the first several years will be concentrated around the headquarters area of the monument.

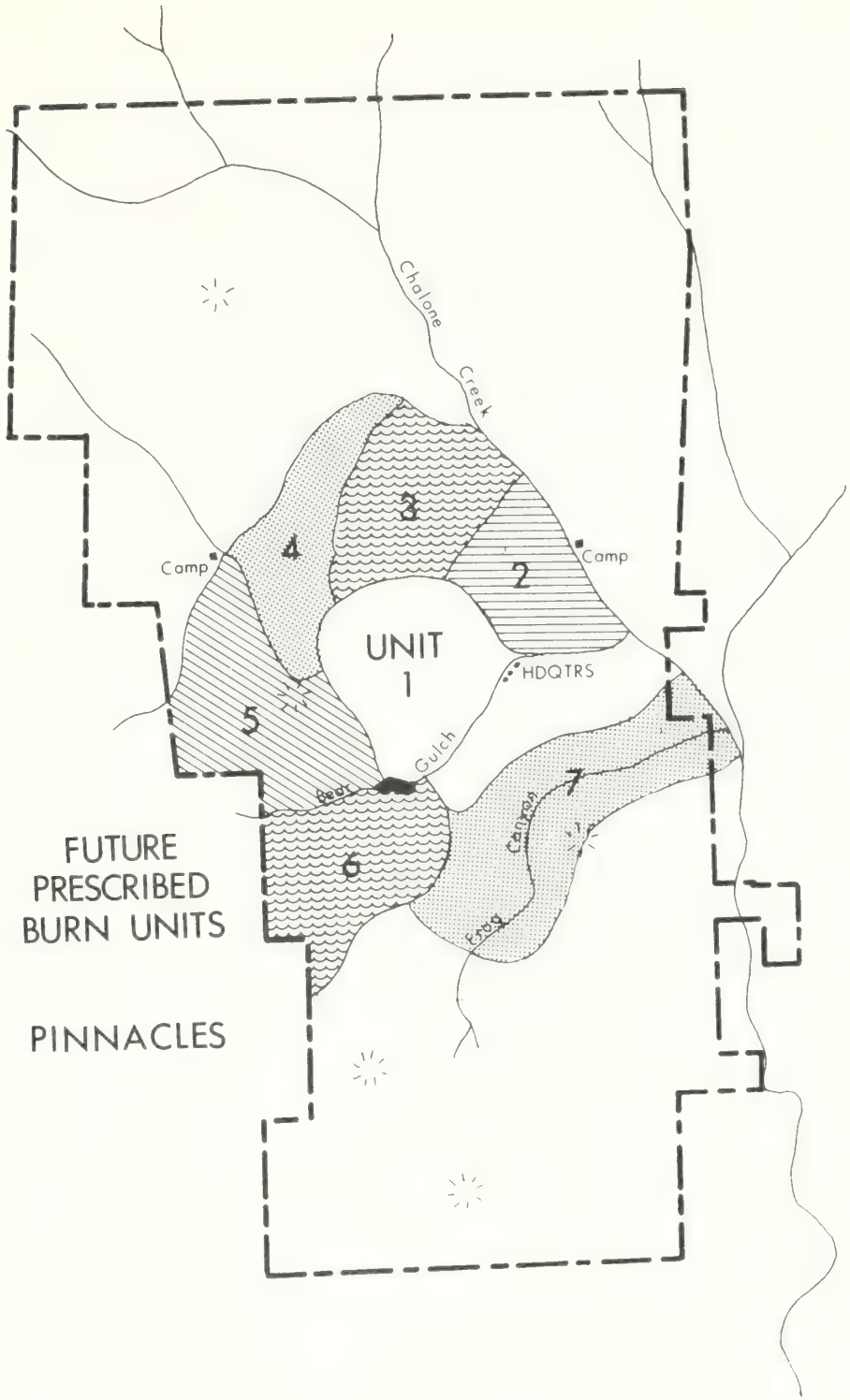

FIGURE 5. Future burning units will occur around Unit 1, but not necessarily in the order shown.

chaparral, 7% foothill woodland-grass, and 13% riparian or xeric sites (Webb 1971). Chaparral is the dense, brushy cover of the hills, and its composition differs on south and north facing slopes. On the south sides, up to 90% of the cover is chamise (*Adenostoma fasciculatum*) with a thin scattering of buckbrush (*Ceanothus cuneatus*), manzanitas (*Arctostaphylos glauca* and *A. pungens*), and other species mixed in. On the north exposures there may be a little chamise but much larger amounts of buckbrush and manzanitas. Other species here are hollyleaf cherry (*Prunus illicifolia*), toyon (*Heteromeles arbutifolia*), western mountain mahogany (*Cercocarpus betuloides*), and California buckeye (*Aesculus californica*). Small quantities of black sage (*Salvia mellifera*) are found in a few spots.

Beautiful digger pine trees (*Pinus sabiniana*) dot the chaparral landscape here and there, arising from grassy openings where rodents and birds probably carried the seeds (Figure 3). Many of the digger pines are infested with dwarfmistletoe (*Aceuthobium campylopodum*), especially where they occur in thick clumps. Throughout the chaparral, except where it is most dense, there may be small areas of annual grasses, the most abundant being foxtail fescue (*Festuca megalura*). Among the chaparral shrubs listed, those that sprout after fire are chamise, hollyleaf cherry, toyon, western mountain mahogany, buckeye, and the oaks. The non-sprouting species are buckbrush and manzanitas.

In the foothills woodland-grass areas, the herbaceous vegetation is composed chiefly of annual grasses and forbs. The shrubs are chiefly California buckwheat (*Eriogonum fasciculatum*), California sagebrush (*Artemisia californica*) and California deerweed (*Lotus scoparius*). All of these may be classed as half-shrubs, being about 2-4 feet tall. At present most of these shrubs are decadent, with much dead material.

Principal trees in the foothill woodland-grass areas are digger pine and California blue oak (*Quercus douglasii*). The latter are long-lived but many of the old trees at the Pinnacles have heart rot and are in poor condition.

The riparian vegetation is comprised mainly of water-loving plants such as willows, cottonwoods, sycamores, blackberries, and ferns. In the Pinnacles area, coast liveoak (*Q. agrifolia*) grows chiefly on the higher chaparral slopes. The riparian community has a copious supply of water in the spring and the winter months, but the stream beds may be entirely dry in summer with only pockets of water here and there.

Deer can have an important bearing on plant successions. They prefer some species over others. After fire, preferred species may be so closely browsed that they are weakened and killed. Species in this category are buckbrush and hollyleaf cherry. When the preferred species are weakened and killed, the non-preferred species increase their proportion in the plant cover. Plants in this category are black sage and chamise. Thus, the carrying capacity decreases with use so heavy that the preferred species are killed out.

Fuel loadings in the chaparral are high over most of the Pinnacles area. A majority of the chaparral has not burned since 1931, and some may not have burned since 1887. Similar conditions exist in the chaparral ecosystems of Sequoia and Kings Canyon National Parks (Parsons 1976). Chaparral normally makes rapid growth after fire and matures in about 15 years. After that time dead materials begin to show through the stand and continue to increase with the age of the chaparral. As the dead materials increase the flammability of the fuels also increase. Although the volume of fuel in the Pinnacles area has not been measured, it is probably in the range of 65000-70000 Kg/ha (30 tons/ac) on the north slope areas of heaviest chaparral. Perhaps one-third to one-half of this is dead material, which becomes extremely dry in summer. In addition to the normal development of dead materials in chaparral, a heavy wet snow from January 3 to 8, 1974, broke much of the chaparral, especially buckbrush and manzanita. This added greatly to the dead fraction of the chaparral at the monument.

Fuels in the foothill woodland-grass are heavy for this type of vegetation because of the high density of half shrubs, which are decadent and have a large proportion of fine dead materials. Fires in this vegetation could move uphill extremely fast in summer.

The fire record, which is not complete and only goes back to 1934, shows that most of the recent fires in the Pinnacles area were man-caused. This is the general situation for most chaparral fires in southern California--at least three-fourths are man-caused. Most are accidental or from carelessness, but some are incendiary. The recent fire record does not give a good idea of how frequently the Pinnacles area burned from lightning fires in the distant past because some lightning fires ignited at great distances away may have spread into the monument area during the long-dry summer. Thus, the one definite lightning fire recorded for the Pinnacles area since 1934 does not mean that only one lightning fire went through the area every 40 years or so. The Indian ignition frequency is totally unknown.

THE FIRE RESEARCH PLAN

The objective of the fire management plan is to restore fire as naturally as possible to the Pinnacles environment to recreate the ecosystem state that would have existed now had natural fires always burned at the monument. The goal of the present research phase is to develop the techniques and prescriptions necessary to achieve that objective. Prescribed fire alone will be used, as natural fires might start in weather that would result in uncontrollable fire behavior in the heavy fuels now present.

Techniques of Burning

Chaparral may be burned under different techniques at three seasons of the year, as follows: upslope strip burning in winter and early spring broadcast burning in the first half of May after the grasses are dry, and broadcast burning soon after the start if fall rains, in late October or in November. All three of these were successfully carried out for a period of 8 to 10 years on the Cow Mountain Recreation Area and adjoining ranches in Lake County (Biswell et al. 1952).

Foothill woodland-grass should be burned after the grasses are dry, perhaps in early May or in the fall around the time of the first rains. Grass is the main fuel that carries the fire.

Such burning as that described above may not exactly simulate the natural fires that occurred before European man arrived on the scene. Unfortunately, we do not know the condition under which those fires burned. It is probable that many of the natural fires in pre-European times burned in mid-summer. Also, as stated earlier the Indians may have burned with light fires in the spring and late fall months.

Upslope strip burning is done when the grass in and around the chaparral is fully green and

at least 2-3 inches high. The burning can continue from this time until the grasses are beginning to dry. This burning will be in the winter and early spring months.

Before burning is started, heavy fuels are located. When the humidity is around 25-30%, the temperature is 70-75 degrees, and little or no wind is blowing, a fire is set with a flamethrower at the base of the slope. The fire will normally extinguish itself at the top of the slope, where the flames no longer dry the vegetation above the fire itself. Ridgetops at the Pinnacle are usually rocky and xeric, mostly covered with grass. If the fires do not go out there, they can be quickly extinguished with backpack pumps that are placed on the ridge above the fire where firefighters are located to see that flames do go out.

One continues burning strips, spaced in the heavier fuels, until the whole of the predetermined fire area has been covered. The after effect can be mosaic of burned and unburned strips.

Broadcast burning after the grasses dry permits the grass fuels to carry the fire from one clump of chaparral to the next. Burning of this sort can be done in the first half of May. The fires are set with drip torches at the tops of ridges and permitted to burn down slope. The burning should be started in the mornings and usually, but not always, stopped in late afternoon. It should be done when there is little or no wind and preferably when the humidity rises late in the day or at night. The humidity should be in the range of 30-35% and the ambient air temperature 70-80 degrees. This burning can be done successfully in foggy weather at the end of a clear day. However, the frequency of these conditions at the Pinnacles are not known.

Broadcasting burning soon after the start of fall rains is similar to that done in the first half of May. The burning is done when the humidity is 25-30% and in those periods when it rises at night. Temperatures may be 70-75 degrees. There should be little or no wind and the forecast should be for similar conditions, with no winds forecast.

Prescriptions for Burning

Precise prescriptions for burning are not available, and will be developed during this research phase. General prescriptions are implied by the above techniques, and these are to be refined. The National Fire Danger Rating System (Deeming et al. 1972) will be used to quantify the range of burning conditions that will be tested. For this purpose, two permanent weather stations have been installed at the monument, and one mobile station will be available at the burn site. Fuel Model B will be used for the heavy chaparral and Fuel Model C will be used for the foothill-woodland-grass vegetation. It is recognized that the slopes with snow-broken mixed chaparral may not fit into Fuel Model B as closely as the more open chamise stands.

Only natural fire breaks (roads and trails, creeks and rocky outcrops, green grass, and past fires) will be used in prescribed burning. These have been located and the predetermined fire management units located accordingly. Superintendent Rod Broyles has directed that no heavy equipment, such as bulldozers and disks, be used in preparing fire breaks on the Pinnacles area. No bulldozers will be used in control of escape fires or wildfires; any such fires will be suppressed only using air attack and ground forces.

The Interim Plan

Several areas have been chosen to begin the prescribed fire program. Eventually, it is planned to burn the monument on a 15-25 year rotation, which would result in 600 to 1000 acres being burned each year. Fire units of this size can be delineated by natural firebreaks, recognizing that not every acre in the unit must burn to meet the objective.

The program will begin in and around the park headquarters area (Figure 4) for three reasons: (1) the area is close and easily accessible for research purposes; (2) fuel hazards to visitors and structures are high and the Superintendent has given this area high priority; and (3) the area is visible to visitors and will place the program in full view for comment and interpretation. Upslope strip burning is planned to begin in winter 1976-77, with utilization of the other techniques in the spring and fall.

Before burning, each area will be characterized by its past fire history, vegetation age, species composition, and fuel weight. Photographic documentation of the area before and during the burn will supplement quantitative descriptions. The various components and indexes of the National Fire Danger Rating System (Ignition, Spread, Energy Release, Burning) will be charted daily and will provide, along with topographic and fuel variations, a prediction of fire behavior. Experimentation with various combinations of burning conditions will continue for the first several years to define upper and lower prescriptive limits, and within those limits, the most effective prescriptions for particular situations.

Once the headquarters area has been treated, the other units, which will likely be concentrically placed around the headquarters unit on natural fire breaks, will be burned (Figure 5).

Restoring fire in chaparral at the Pinnacles will be the first effort at prescribed burning in this type of vegetation on National Park System lands. We know that fire plays an important role in this type of vegetation. Principally it reduces the fuels, creates new age classes, and is generally essential for the maintenance of the vegetation as chaparral. The objective of the prescribed burning will be to simulate, to the fullest extent possible, the influence of natural fire on the chaparral and foothill woodland-grass ecosystem of Pinnacles National Monument.

LITERATURE CITED

AGEE, J. K. 1974. Fire management in the national parks. Western Wildlands 1(3):27-33.

BISWELL, H. H., R. D. TABER, D. W. HEDRICK, and A. M. SCHULTZ. 1952. Management of chamise brushlands for game in the north coast area of California. Calif. Fish and Game 38(4):453-484.

BISWELL, H. H.1974. Effects of fire on chaparral. *In* Fire and Ecosystems, edited by T. T. Kozlowski and C. I. Ahlgren. Academic Press, New York, pp 321-364.

DEEMING, J. E., J. W. LANCASTER, M. A. FOSBERG, R. W. FURMAN, and M. J. SCHROEDER. 1972. The natural fire-danger rating system. USDA Forest Service Res. Rep. RM-84. Rocky Mtn. For. and Range Expt. Sta. Fort Collins, Colo.

JEPSON, W. L. 1921. The fire-type forest of the Sierra Nevada. Intercollegiate Forest Club Annual 1:7-10.

PARSONS, D. F. 1976. The role of fire in natural

communities: an example from the southern Sierra Nevada, California, Environ. Cons. 3(2): 91-99.

PHILPOT, C. A. 1973. The changing role of fire on chaparral lands. pp 131-150 *In* Symposium on living with the chaparral. Univ. Calif. Riverside, March 30-31, 1973.

USDA, Soil Conservation Service. 1969. Soil survey of San Benito County, California. 111 p.

USDI, National Park Service. 1972. Part two of the National Park System plan: Natural history, Washington, D. C. 140 p.

_____. 1975. Proposed master plan. Pinnacles National Monument, California. 90 p.

_____. 1975. Proposed Natural Resources Management Plan. Pinnacles National Monument, California. 78 p.

WEBB, R. C. 1971. A guide to the plants of the Pinnacles. Southwest Parks and Monuments Assn. in cooperation with the National Park Service and Pinnacles National Monument. 76 p.

FIRE-RESILIENT FORESTS OF DOUGLAS FIR IN OLYMPIC NATIONAL PARK: AN HYPOTHESIS

R.W. Fonda[1]

INTRODUCTION

In 1969 Larry Bliss and I described the montane and subalpine forest vegetation of the Olympic Mountains (Fonda and Bliss 1969). We considered that the eastern montane forests dominated by Douglas fir (*Pseudotsuga menziesii*) were seral, and that western hemlock (*Tsuga heterophylla*) would eventually dominate those slopes. This is the prevailing regional view of the role of Douglas fir in the Pacific Northwest (U.S. Forest Service 1965). Douglas fir is an invading species, especially after fire; it is shade intolerant and therefore forms a one-generation, even-aged forest. Douglas fir can live 500-1000 years, but eventually it should yield to more tolerant species.

In marrying the concepts of succession and ecosystem function, Odum (1969) provided a new basis for evaluating succession. Many of the characteristics typified by the stable community, however, do not obtain in communities dominated by long-lived seral trees. Douglas fir is a long-lived, invading tree species that dominates forests in which stability is achieved before the sociologically determined climax. That is, the community has reached a functional stage of homeostasis, but the populations are not yet stable.

Holling (1973) presented a well-argued comparison between stability and resilience. He utilized the functions of species populations to describe their relationships with one another, and showed how population dynamics could be interpreted functionally. Holling argued that species are related through time in a number of ways, some of which are beneficial and cause the continued survival of the species. Other relationships, however, could cause the extinction of a species. Figure 1 follows changes in two populations through time, plotted on separate graphs. Early in this relationship the two populations are not in close communication, and the curves swing widely; through time, however, the populations become more closely related, so that the curves are damped. Graphing in this way allowed Holling to view fluctuations in species populations as intersections on the phase plane, and to trace the inward spiral of intersecting points for two closely related populations. An outward spiral in the phase plane indicates populations that diverge from one another. Figure 2 shows both inward and outward spirals. Holling was most concerned with inward spirals, which would eventually describe a stable cycle on the phase plane. The area in which the cycle is stable was called by Holling the domain of attraction (Fig. 2). Homeostatic mechanisms maintain the relationships of species within the boundaries of the domain of attraction. Outside the domain of attraction, however, is stress, where homeostasis may fail. Domains of attraction are a facet of the niche structure of the community.

Holling's concept can be used conceptually to assess stability in communities of long-lived invading species. Those communities in which species maintain domains of attraction despite minor environmental perturbations are stable. In stable communities organisms tolerate perturbations. Resilient communities comprise species whose domains of attraction could be destroyed, yet which are able to re-establish them. In resilient communities, organisms are killed by perturbations. Both stability and resilience are characteristics of natural communities.

In the past several years our thinking has changed about the role of natural fire in ecosystem structure and function. Many forests and grasslands depend on fire for maintenance and survival. Such communities are fire dependent, or to use terminology consistent with Holling's concept, "fire-stable." Species of fire-stable communities maintain their domains of attraction despite the perturbation of fire. Extending this concept, "fire-resilient" communities are those whose species are destroyed by fire, yet which can re-establish the domains of attraction.

Such a fire-resilient community is dominated by Douglas fir in the eastern Olympics. I believe now that the role of Douglas fir is different from that stated earlier (Fonda and Bliss 1969). In this paper I present the hypothesis that forests dominated by Douglas fir in the eastern Olympics are fire-resilient, and further that this contrasts with the concept of fire-stable communities.

FIRE HISTORY OF THE EASTERN OLYMPICS

There is extensive evidence that a series of large fires burned most of the montane vegetation in the eastern Olympics about 300 years ago. Increment borings from old Douglas firs in the eastern drainages of the Olympics indicate that almost all are 280-300 years old. Only on exposed, south-facing ridges is there much variability; here they are 180-300 years old. Western hemlocks from the eastern standa are less than 200 years old, except on north-facing slopes where they are approximately the same age as the Douglas firs with which they are associated. This suggests that most of the burned slopes were occupied by Douglas fir shortly after the catastrophic fires. Douglas fir may have re-invaded exposed south-facing slopes more slowly because of the hotter and drier microclimate, or there may have been more recent fires.

Morse Creek drains a large part of the mountains immediately south of Port Angeles. In this basin are a few Douglas firs that are 500-550 years old. These trees probably germinated after a fire about 550 years ago, and survived more recent fires. I have never found a stand of 500 year old Douglas firs, or of any other species, in the eastern montane zone. Most commonly the 500 year old trees were found in forests of Douglas firs that were less than 100 years old.

The eastern Olympics support extensive stands of Douglas firs that are 75-100 years old. Based on ages of Douglas fir trees, I hypothesize that there have been at least three recent periods of major wildfires in the Olympics. These fires were centered on 550, 300, and 100 years BP. I have no data on the composition of the forests that burned, but there is nothing to suggest that the forests consumed by the fires were dominated by the climax species western hemlock. Rather,

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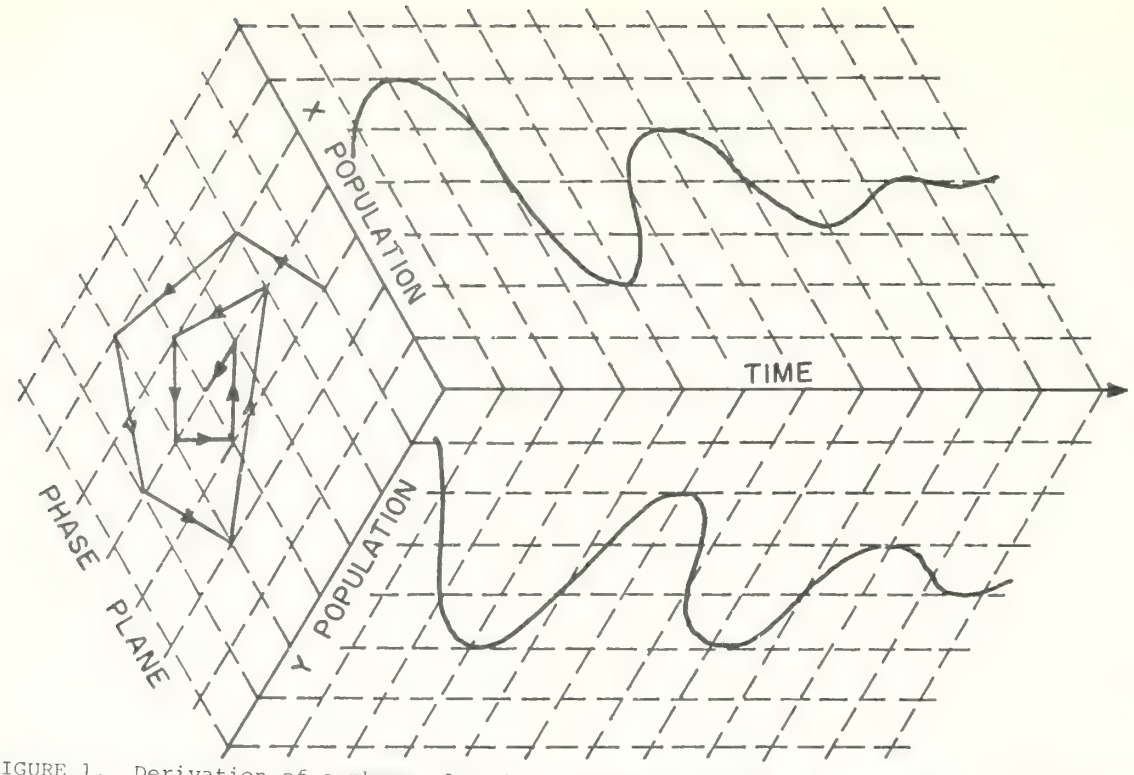

FIGURE 1. Derivation of a phase plan for interactions of two populations. Points of population intersection are seen on the phase plane, and the inward spiral that they describe is typical of populations that develop a close relationship with each other, through time. (After Holling 1973.)

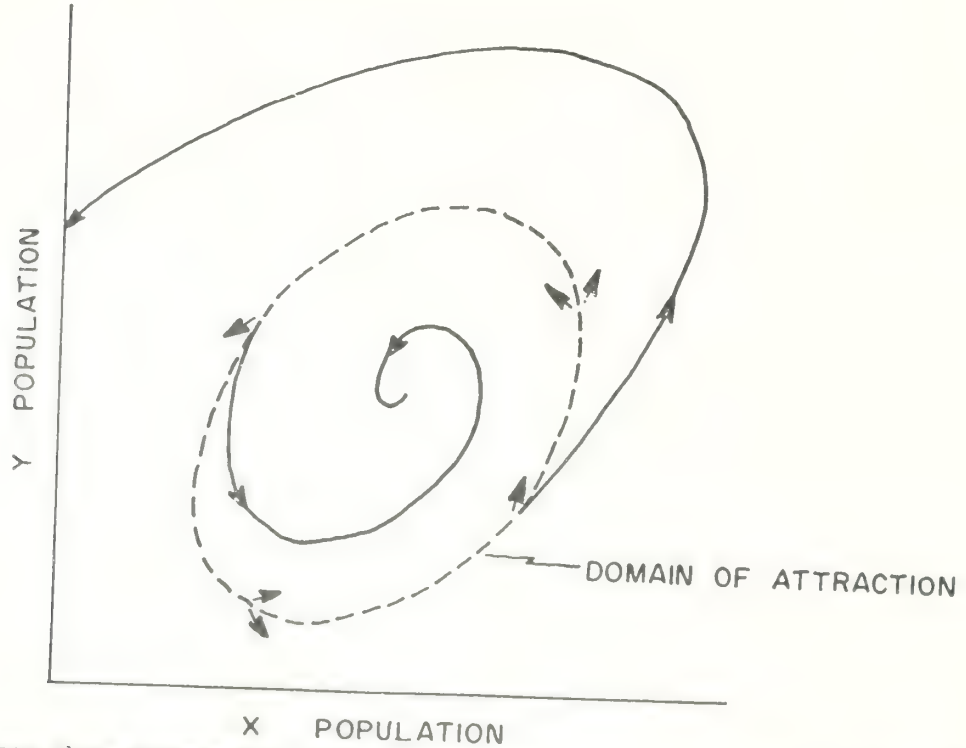

FIGURE 2. phase plane for two populations, showing two possible kinds of interactions. The outward spiral is typical of two populations that are diverging from one another. The inward spiral, typical of two closely related populations, eventually stabilizes inside the domain of attraction, which is described by the dashed line. (After Holling 1973.)

TABLE 1. Mean tree density per hectare for important tree species in different aged Douglas fir stands in the eastern Olympic Mountains. Data for 300 year forests are means of several stands; those from younger forests are means from one stand. From Fonda and Bliss (1969).

Aspect	East	North	Exposed south	South	North
Age (yrs)	65	90	300	300	300
Douglas fir	1236	778	554	353	232
Western hemlock	82	704	20	185	109
Western redcedar	37	148	-	22	49

TABLE 2. Principal understory species in Douglas fir forests, Olympic Mountains.

Recent clearcut	65-90 years	300 years
Holodiscus discolor		
Rubus parviflorus		
Ribes lacustra		
Symphoricarpos albus		*S. albus*
Berberis nervosa	*B. nervosa*	*B. nervosa*
Vaccinium parvifolium	*V. parvifolium*	*V. parvifolium*
Achlys triphylla		*A. triphylla*
Rosa gymnocarpa		*R. gymnocarpa*
Polystichum munitum		*P. munitum*
Rubus spectabilis		
Rubus ursinus		
Epilobium angustifolium		
Cirsium edule		
Anaphalis margaritacea		
	Gaultheria shallon	*G. shallon*
	Linnaea borealis	*L. borealis*
	Chimaphila umbellata	*C. umbellata*
	Viola adunca	

with the relatively short time period between fires, I believe that there must have been a significant amount of Douglas fir in all forests.

SUCCESSION AFTER FIRE

Here I presume a series of catastrophic, hot fires, that destroyed all vegetation including Douglas fir. Succession after fire clearly involves Douglas fir and changes in the population structure of Douglas fir. Douglas fir rapidly invades burned sites, but its density declines with time (Table 1). Western hemlock enters these stands about 50-100 years after fire, and all data associated with western hemlock indicate that it should be the climax tree, if there were no fires.

The destroyed area initially would be invaded by shurb species, many of which would have been original components of the pre-fire forests. The most extensive data available on this kind of re-invasion comes from studies of clearcut, slash-burned areas. On such sites in the Oregon Cascades, Yerkes (1960) found that the principal dominants were species that were originally present in the forest before the disturbance. I examined clearcuts on U.S. Forest Service land in the montane zone of the Dungeness drainage in the Olympics, and found agreement with the work of Yerkes. Most clearcuts in the Dungeness drainage were dominated by *Holodiscus discolor* and *Rubus parviflorus*, with significant amounts of *Symphoricarpos albus* and *Ribes lacustre* (Table 2). There were many Douglas fir seedlings, and also some western hemlocks, but neither was present in amounts normally found in a 65 year old forest (Fonda and Bliss 1969).

Shrubs and trees that are present in the undisturbed forest are called "originals"; many of the original species can re-establish the former niche structure after complete destruction of the forest. Only a few of the species that currently dominate the clearcuts (e.g., *Holodiscus discolor, Rubus parviflorus, Anaphalis margaritacea, Cirsium edule*) are not members of the closed montane forest community. They will be eliminated by competition with the original shrubs and trees. Fonda and Bliss (1969) found that by 65 years Douglas fir and the original understory species are well-established on a burned site (Table 2). These species were consistently found in 300 year old forests.

FIRE RESILIENCE

My data on succession in the montane zone of the eastern Clympics suggest that at least once every 150-300 years a long period of dry weather coincided with a high fuel supply to support massive and widespread fires, so that most of the forests burned completely. It is probable that the burned forests were dominated by Douglas fir, because of its long life span and the short time between

fires. Succession quickly re-established the dominant tree and understory species of the Douglas fir communities, and the forests matured to a point at which wildfire was possible again. This maintained Douglas fir as a dominant species, and it also prevented western hemlock from dominating the forests. Fire suppression by man is the only factor that could interfere with this cyclic relationship between fire and Douglas fir communities.

This situation is different from fire-stable communities, in which species survive relatively cool ground fires with their domains of attraction not significantly disrupted. The catastrophic fires that burned in the eastern Olympics must have been hot crown fires, which none of the species would have survived.

My comments in this paper apply only to the eastern Olympics. Although I suspect that the concept of fire-resilience may apply throughout the Douglas fir zone, I do not have the necessary data to support extending the hypothesis beyond the eastern Olympics.

LITERATURE CITED

FONDA, R.W. and L.C. BLISS. 1969. Forest vegetation of the montane and subalpine zones, Olympic Mountains, Washington. Ecol. Monogr. 39: 271-301.

HOLLING, C.S. 1973. Resilience and stability of ecological systems. Ann. Rev. Ecol. Syst. 4: 1-23.

ODUM, E.P. 1969. The strategy of ecosystem development. Science 164:262-279.

U.S. FOREST SERVICE, Division of Timber Management Research. 1965. Silvics of forest trees of the United States. U.S.D.A. Handbook 271. 762. p.

YERKES, V.P. 1960. Occurrence of shrubs and herbaceous vegetation after clear cutting old-growth Douglas fir in the Oregon Cascades. U.S. For. Serv. Res. Paper PNW-34. 12 p.

MOOSE-FOREST-FIRE ECOLOGY IN ISLE ROYALE NATIONAL PARK

Robert A. Janke[1]

INTRODUCTION

This study is a phase of a long-term research project on the ecology of the upland boreal forest type on Isle Royale National Park. It is concerned with relationships between moose, fire, and the forest ecosystem.

Isle Royale National Park is an archipelago comprised of one large island about 72 km long and 14 km wide and numerous small outlying islands in western Lake Superior. The boreal forest-type covers the outlying islands and the portions of the main island nearer to Lake Superior. It is dominated by balsam fir (*Abies balsamea*), white spruce (*Picea glauca*), white birch (*Betula papyrifera*) and quaking aspen (*Populus tremuloides*). A temperate deciduous type forest dominated by sugar maple (*Acer saccharum*)and yellow birch (*Betula alleghaniensis*) occupies a smaller area of land in the interior portions of the mainland more remote from the climatic influence of Lake Superior.

White man settlement of Isle Royale in the early 1840's was soon followed by copper mining activity which lasted until about 1900. During this period large areas of forest land were burned over to facilitate prospecting for copper. More recently, in 1936, a large fire burned about 20% of the land area of the park.

Moose are reported to have first inhabited the park some time between 1906 and 1913 (Murie 1934; Hickie 1936). The population reached an all-time high about 1930 at which time severe over-browsing was noted (Brown ca. 1935). Since then the population declined, and, although some fluctuation has occurred, has become relatively more stable. Signs of moose browsing, however, are conspicuous throughout most of the park.

Fire and moose appear to be the two most important environmental influences affecting Isle Royale forests. For this reason, our study has emphasized these two parameters.

METHODS

To study the effects of moose browsing on the forest, study areas were established on several outlying islands and one long narrow peninsula all similarly exposed to the environmental influences of Lake Superior (Fig. 1). The selected study areas had been exposed to varying degrees of browsing. The comparative degree of browsing for each was determined from observation of past browse conditions and moose habitation reported in the literature or described by local residents who were interviewed, and by checking present conditions in a thorough reconnaissance of all study areas. In this reconnaissance, browse lines and the presence of American yew (*Taxus canadensis*) were noted. The latter shrub was once the prevailing ground cover throughout Isle Royale (Adams 1909; Cooper 1913) but is now practically absent from the main island. Its presence is considered a reliable indicator of the scarcity or absence of moose (Bergerud and Manuel 1968; Pimlot 1953). Combining all this information, it was determined that Passage, Smithwick and Raspberry Islands have been, for all practical purposes, untouched by moose, while Mott and Caribou Islands and Blake Point have been browsed. Browsing on Mott and Caribou has been moderate and that on Blake Point, intense.

As a check on the above, for recent years at least, circular pellet plots were established along randomly selected lines in each study area. These were 12 m in diameter and spaced 30 m apart.

Vegetational parameters were measured in each study area along randomly selected lines perpendicular to the long axis of each study area. Tree (stems greater than 5 cm diameter) density and basal area were sampled by the point-quarters method (Cottam and Curtis 1956) with 15 m spacing between sampling points. At every other point, the four trees sampled were aged with an increment borer.

Tree seedling (stems less than 0.5 m in height) densities were measured in a 1 x 1 m square plot and saplings (stems greater than 0.5 m high and less than 5 cm diameter), in a 2 x 5 m plot at each sampling point. Shrubs (woody stems greater than 0.5 m tall and less than 5 cm diameter) were sampled using a Canfield line-intercept method (Hoskins and Dalke 1966) in 10 m segments of the tree sampling line behind each sampling point. For each shrub intercepted an estimate was also made of the average height. The presence of low vascular plant species and the total lichen and bryophyte cover were recorded in each of the 1 m^2 tree seedling plots.

In order to study post-fire succession and the ecology of tree reproduction as related to various stages of succession, sampling was done in about 230 plots, each 16 m in diameter along 17 transects oriented perpendicularly to the main topographic features of the park (most of which are in approximately a northeast-southwest direction). About 90 of these plots are in the 1936 burn forest, while the remaining 140 plots are in stands of varying age. Ages of these stands were estimated by increment borings on four of the largest trees in the stand. The species and D.B.H. of all trees within each plot were recorded. Seedling and sapling densities were determined from a smaller plot 8 m in diameter concentric with the tree plot. The microhabitat (litter, decayed wood, moss, etc.) of each seedling was also noted. The availability of each soil microhabitat type was determined by a line-intercept method using two 8 m line segments perpendicular to the transect line. Soil litter depths (Aoo and Ao horizons) were measured at six points within the seedling plots.

RESULTS

Moose and the Forest Ecosystem

The results of the pellet counts (Table 1) indicate that in recent years, there has been little, if any, browsing on Smithwick, Passage, and Raspberry Islands, moderate browsing on Mott and Caribou Islands and heavy browsing on Blake Point. It

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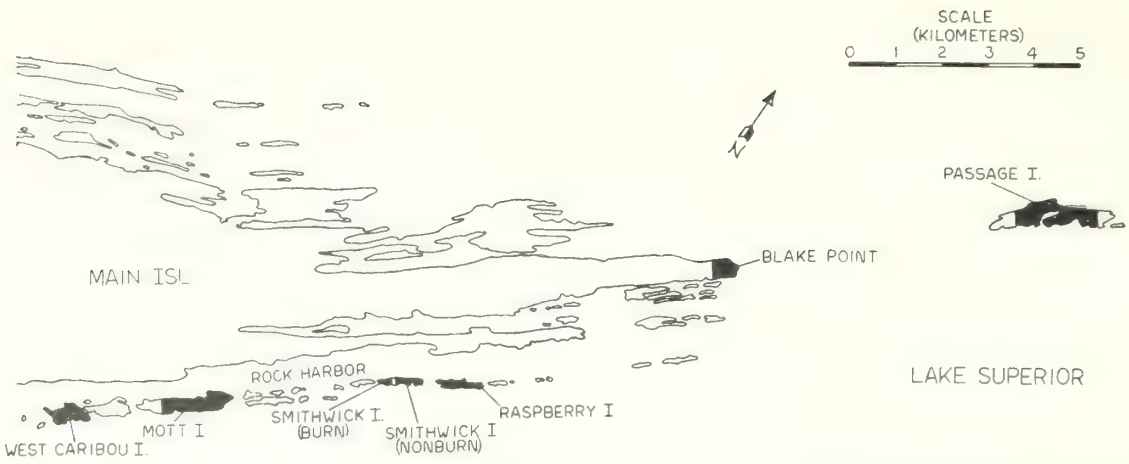

FIGURE 1. Map of northeast end of Islae Royale National Park. Blackened areas are study sites.

TABLE 1. Pellet group density and confidence intervals (P = 0/05).

	Blake Pt.	Mott I.	W. Caribou I.	Smithwick I. (unburned)	Passage I.	Smithwick I. (burned)	Raspberry I.
Pellet groups per ha	655	230	177	0	0	0	0
Confidence interval	±175	±108	±61	0	0	0	0

TABLE 2. Quantitative forest parameters of each study site.

	Blake Pt.	Mott I.	W. Caribou I.	Smithwick I. (unburned)	Passage I.	Smithwick I. (burned)	Raspberry I.
Tree density (stems/ha)	803	677	598	1490	1313	3953	1980
Basal area (m^2/ha)	26.3	26.0	20.8	30.2	19.8	40.4	27.7
Basal area per tree (m^2)	0.033	0.038	0.035	0.020	0.015	0.010	0.014
Sapling density (stems/ha)	11300	4700	4000	10400	3500	3500	7800
Seedling density (stems/ha)	53400	12300	8600	26900	10400	52700	17100
% shrub cover	17.0	39.6	50.4	43.1	51.7	13.4	47.5
Average shrub height (m)	0.58	0.73	0.90	1.35	1.18	1.70	1.54
% low vascular ground cover	56	51	50	27	25	25	13
% bryophyte cover	17	4	5	6	15	14	7

should be noted that two study areas were used for Smithwick Island, one on a recently burned portion (about 85 years ago) and the other on a portion which has no recent history of fire. The pellet survey results are in line with our original assumption about relative browse intensity based upon reports from the literature and our observations of browse condition.

A comparison of general forest attributed for the 7 moose study sites is shown in Table 2. The overall tree densities for the browsed sites are considerably less than those of the unbrowsed sites. Basal area per tree, however, is significantly greater on browsed sites. It seems probable that thinning of the stand by moose browsing has stimulated the growth of the remaining trees. Tree seedling and sapling densities are not significantly different on browsed and unbrowsed sites. The tree density differences noted above, then, are probably not due to differences in reproductive potential on the two kinds of sites.

Average height of shrubs are significantly less on browsed sites than on unbrowsed sites, but no such differences exist in shrub cover. This lack of a difference in shrub cover may be due to lateral sprouting stimulated by browsing. Percent cover of low vascular plants is significantly greater on the browsed sites but percent bryophyte cover is not significantly different.

Differences in density of various tree species are shown in Table 3. Balsam fir and mountain ash, both important moose browse species, are significantly less dense on the browsed sites than on the others; whereas white spruce, rarely used by moose, is significantly more dense on the browsed sites. This greater density of white spruce may be a response to reduced competition from fir. Although white birch is an important browse species, no significant difference exists between the two types of sites. For all species, there are no significant differences in seedling and sapling densities.

Fire and the Forest Ecosystem

From the ages of trees sampled in the moose study plots, age structure diagrams were constructed (Fig. 2). From these, some successional trends are evident. Smithwick Island Unburned represents a site with no recent history of fire or of moose browsing. Balsam fir alone dominates the site. The roughly pyramidal shape of the fir diagram indicates that this species will continue to dominate. White birch and mountain ash continue to maintain low level populations. Blake Point also has no recent fire history but signs of heavy browsing have been observed earlier than 1930 (Brown ca 1935). The age structure diagram shows declining importance of birch and spruce. Fir increased in importance up until about 80 years prior to the date of tree boring (1970) and then was abruptly curtailed. Seedlings established at that time would have become of browsable size about the time that moose arrived on Isle Royale. This diagram is in striking contrast to that for Smithwick Island Unburned.

The diagram for Smithwick Island Burn shows successional trends following a fire in about 1910 in an area not inhabited by moose. Birch invaded the area first, then became less important as fir invaded a few decades later. The stand is now extremely dense in fir. (Note that the density scale in this diagram differs from the others.) The apparent reduction in densities of trees less that about 45 years of age is due to the fact that only trees greater than 5 cm diameter were bored. Passage and Caribou Islands were burned about the same time, but Caribou has been moderately browsed while Passage has not. The decline in birch with time is evident in both. Both also show a tendency for fir to increase, but for Caribou Island this tendency was somewhat curtailed by moose browsing.

Based on data from the 230 circular plots, graphs (Figs. 3-10) of various forest parameters as related to time since last fire (stand age) were constructed. Each point represents an average of all plots of a similar age range, the number varying from 11 to 20. The point on the extreme left, however, represents the average of all 90 plots in the 1936 burn. The graphs of white birch (Fig. 3) and quaking aspen (Fig. 4) relative basal area show no detectable trends with increasing stand age. A plot of the sum of birch and aspen relative basal area (Fig. 5), however, displays a declining trend in this quantity with time. This is what would be expected of post-fire pioneer shade-intolerant species and, indeed, that is the role which birch and aspen play in post-fire succession on Isle Royale. The lack of a trend in the individual graphs for birch and aspen is probably because either one or the other or both may act as the pioneer tree generation in any given stand.

The relative basal area for balsam fir (Fig. 6) generally increases for stands up to about 165 years of age, then becomes stable. This is a normal behavior for a shade tolerant species. White spruce behaves like a shade tolerant species only at the older stand ages (Fig. 7). Here it is evidently replacing birch and aspen which are on the decline even beyond a stand age of 215 years. Spruce may well have an advantage over fir in this regard in that the older trees do not die or become windfalls as readily as fir, nor has its reproduction been browsed by moose. The graph of the sum of fir and spruce relative basal area (Fig. 8) indicates that as post-fire succession proceeds there is a steady increase in conifers at the expense of the broad-leafed deciduous species.

From the soil microhabitat data the total percentage of the ground covered by decayed or undecayed logs was plotted against stand age (Fig. 9). This quantity exhibits a definite upward trend with increasing stand age. The depth of the A_o portion of the soil litter layer also increases with stand age but levels off at about 4 cm (Fig. 10).

From the circular plot data a diagram (Fig. 11) was constructed, showing relative densities of balsam fir for various diameter classes in 2 cm increments. Normally, diameter-class densities would be expected to become progressively larger with decreasing diameter. This diagram, however, shows a conspicuous dip in the curve in the 2-13 cm range. This suggests that moose have had a significant effect upon the densities of the younger fir trees.

DISCUSSION

As a result of moose browsing on Isle Royale for approximately the past 65 years, the upland boreal type forest has been dramatically altered. The density of trees has greatly declined, but the average tree diameter has increased. The density reduction is mostly attributable to the reduction in fir density caused by browsing on this species. This reduction has mostly affected the younger age classes of fir since the older trees were beyond reach of moose at the time the latter arrived on Isle Royale. To a smaller extent the reduction in total tree density may be attributed to the near elimination of mountain ash trees by browsing. The increase in average tree diameter may be, in part, the direct effect of elimination of trees of smaller diameter. It may also be, in part, a

TABLE 3. Densities of trees, saplings and seedlings of major tree species in stems/ha.

	Blake Pt.	Mott I.	W. Caribou I.	Smithwick I. (unburned)	Passage I.	Smithwick I. (burned)	Raspberry I.
Balsam fir							
trees	409	259	363	948	890	2964	1011
saplings	6160	4130	3290	6340	3080	2680	7540
seedlings	26500	9300	5400	12500	4200	44500	8300
White birch							
trees	243	170	171	150	105	943	825
saplings	2400	0	290	1220	0	230	42
seedlings	19000	450	1400	9400	2700	1800	1700
White spruce							
trees	138	164	48	26	0	0	21
saplings	160	0	110	63	0	0	0
seedlings	610	0	0	0	0	0	0
Mountain ash							
trees	4	6	5	373	246	45	124
saplings	2260	100	290	2660	270	450	210
seedlings	7300	1000	1800	5000	2500	6400	7100
Aspen							
trees	0	62	0	0	0	0	0
saplings	60	370	0	0	0	0	0
seedlings	0	890	0	0	0	0	0

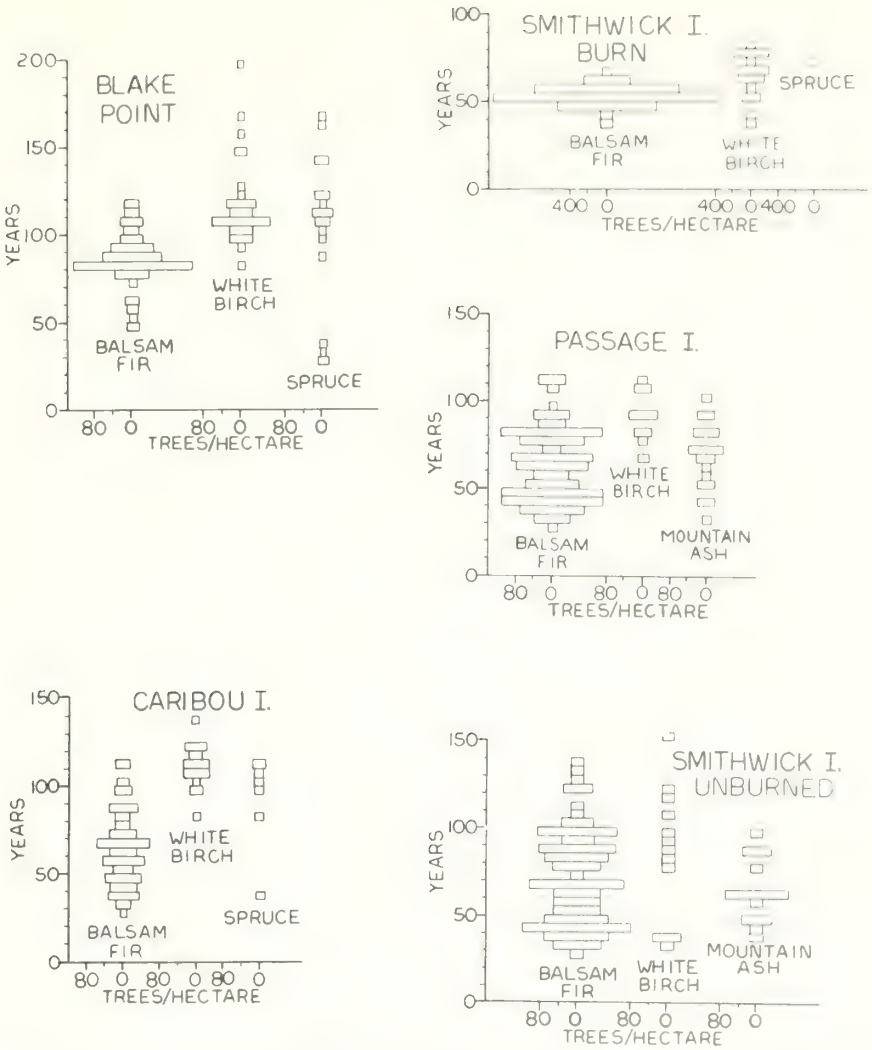

FIGURE 2. Age structure diagrams for five study sites. Note that Smithwick I. burn has a different density scale than the other sites.

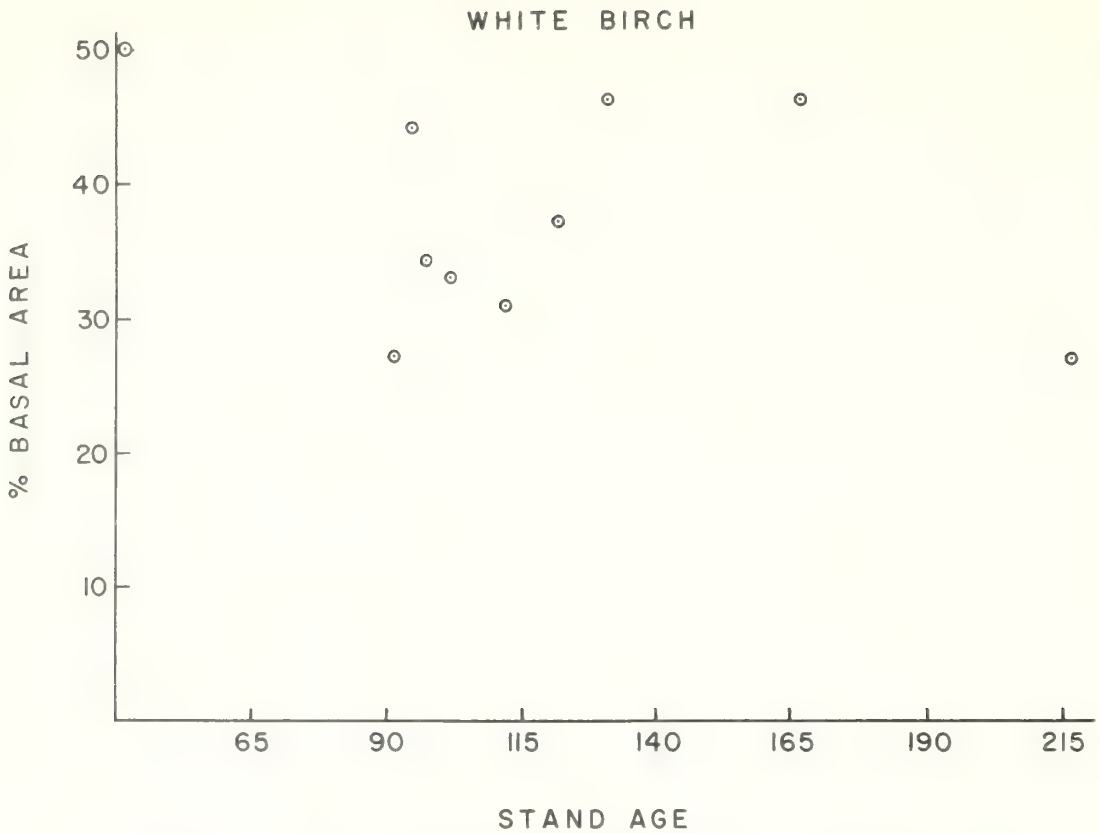

FIGURE 3. Relative basal area of white birch versus stand age.

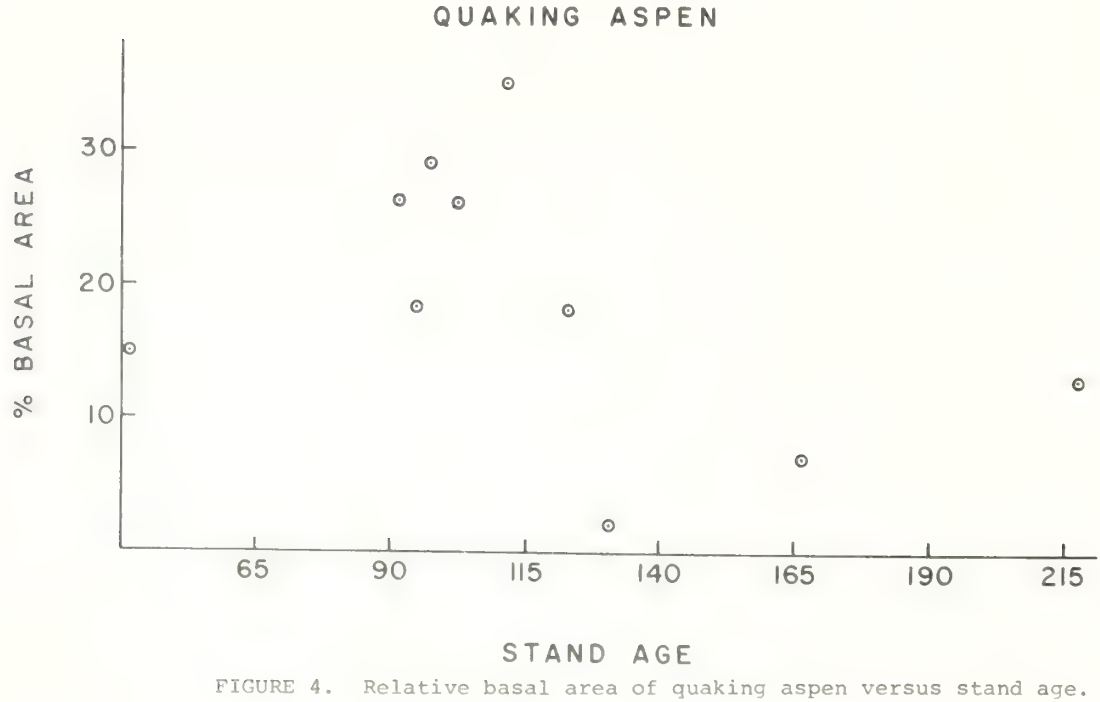

FIGURE 4. Relative basal area of quaking aspen versus stand age.

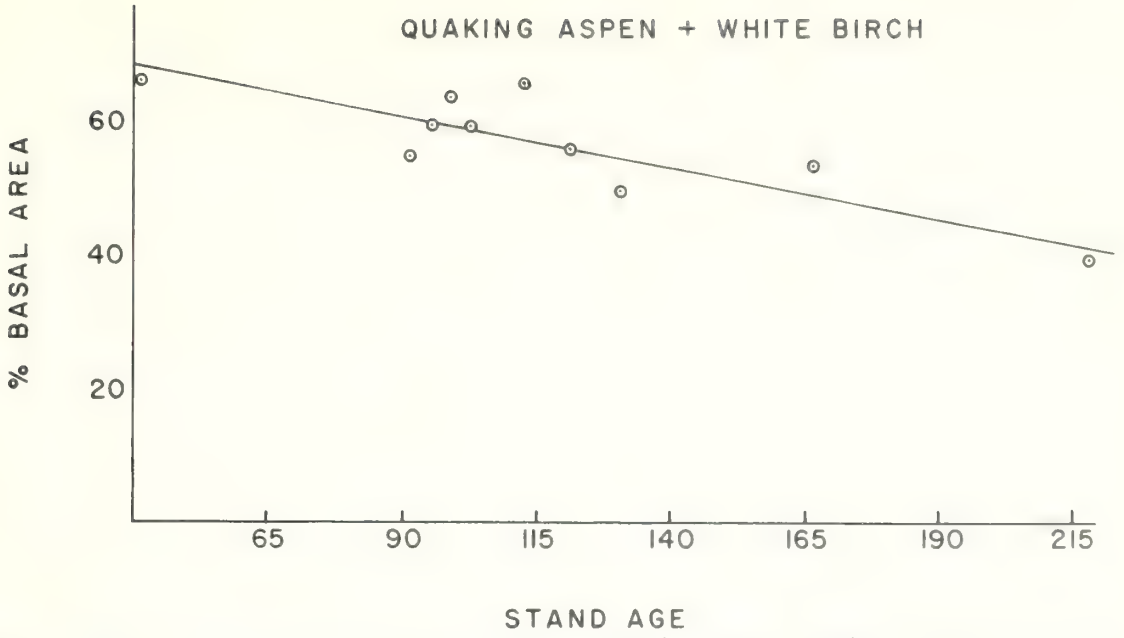

FIGURE 5. Relative basal area of white birch and quaking aspen combined versus stand age.

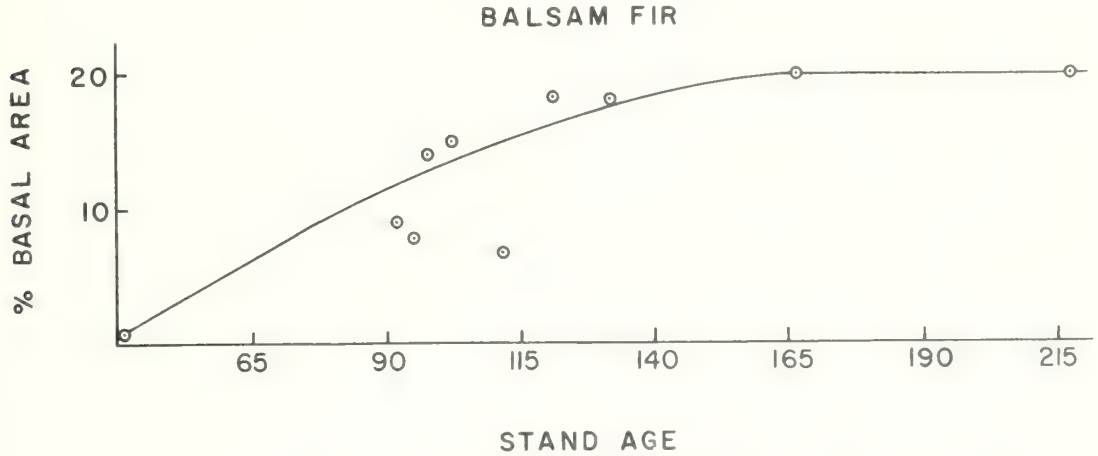

FIGURE 6. Relative basal area of balsam fir versus stand age.

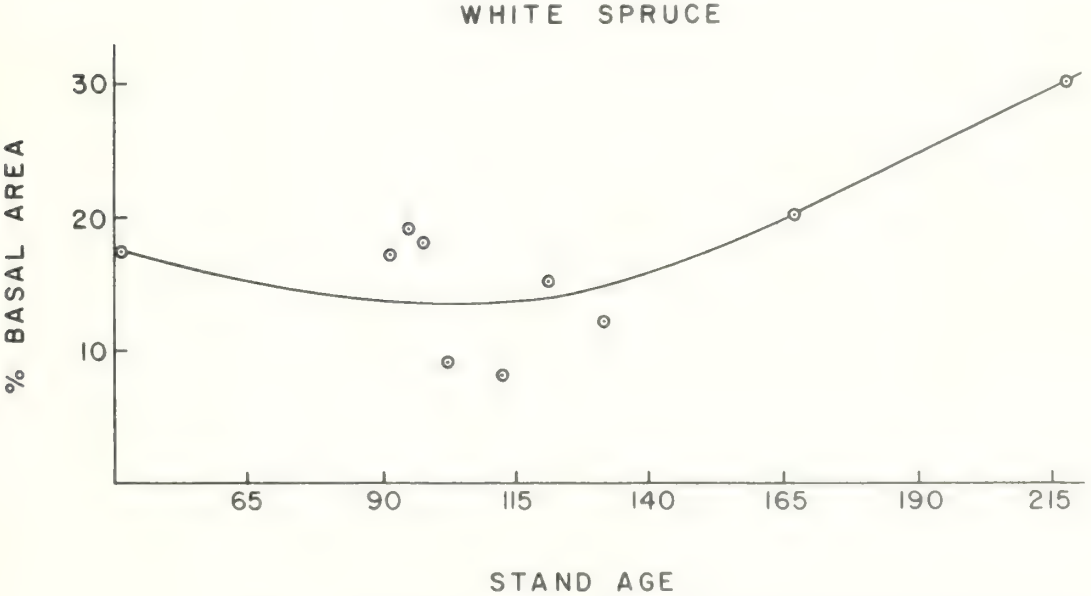

FIGURE 7. Relative basal area of white spruce versus stand age.

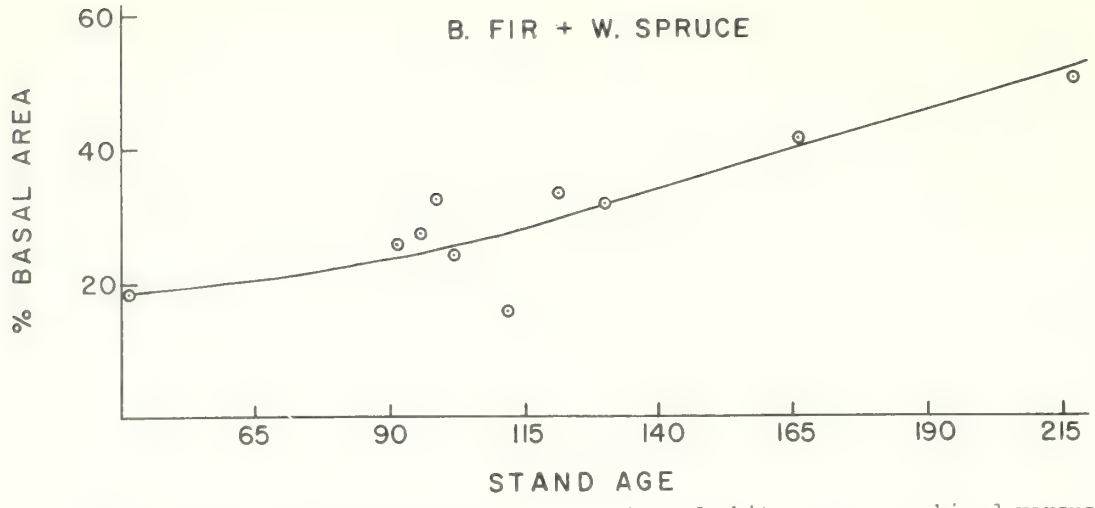

FIGURE 8. Relative basal area of balsam fir and white spruce combined versus stand age.

FIGURE 9. Percent of ground covered by decayed or undecayed wood versus stand age.

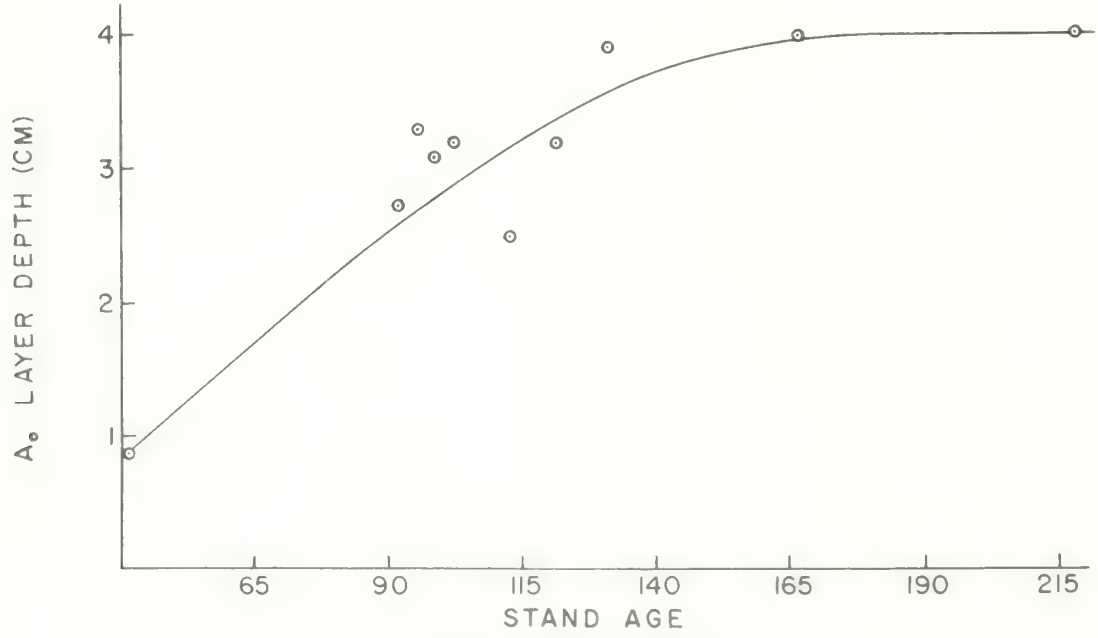

FIGURE 10. Depth of soil A_o layer versus stand age.

FIGURE 11. Relative densities (%) of balsam fir for various diameter classes in a 2 cm increments.

result of increased growth rate due to thinning of the tree layer. The reduction in overall tree density and the increase in average tree diameter, together with a reduction in average shrub height in moose-browsed stands, have created forests which are more even-aged, open, and parklike as compared to pre-moose forests. This, in turn, may have reduced the susceptibility of the forest to crown fires, especially since there are fewer low conifers to bridge the gap between the ground, where most fires start, and the tree canopy.

It is not obvious why low ground cover plants are more abundant in the browsed stands. This could possibly be due to increased light on the ground because of removal of lower branches of balsam fir and reduction of the shrub canopy.

White birch, though a browse species, was relatively unaffected by moose browsing in the study areas. The succession studies indicate that this is the major pioneer species in the boreal forests of Isle Royale, and that in time it tends to be replaced by spruce and fir. By the time moose arrived, therefore, much of the birch may have been out of reach of moose in the study areas. This would be true for most of Isle Royale upland boreal type forests except for the areas burned in 1936. In the latter, moose must have fed heavily on young birch and aspen for several decades after the fire. Despite this, birch survives today in the 1936 burn area as the major dominant (see point nearest left, Fig. 3) in stands of relatively high density.

A major trend in post-fire succession is the gradual replacement of broad-leaf deciduous tree species by conifers. Moose have modified the coniferous element by increasing the importance of white spruce at the expense of balsam fir. Other post-fire trends are an increase in the soil litter depth and an increased amount of wood covering the forest floor. The latter is undoubtedly due to an increase in the incidence of windthrow as the trees become larger and older. All of these trends tend to increase the inflammability of the forest as post-fire succession proceeds.

At the time of this conference, only a part of the data collected in the field has been processed. We shall continue our search for post-fire successional trends among the 230 plots. Then, using data from these same plots, we will explore relationships between tree seedling establishment and the important environmental factors associated with post-fire succession.

LITERATURE CITED

ADAMS, C.C. 1909. An ecological survey of Isle Royale, Lake Superior. Report from the Univ. of Mich. Museum. Publ. by the State Biol. Survey as part of the Geol. Survey of 1908.

BERGERUD, A. and F. MANUEL. 1968. Moose damage to balsam fir--white birch forests in central Newfoundland. J. Wildl. Manage. 32:729-746.

BROWN, C.A. ca 1935. Ferns and flowering plants of Isle Royale, Michigan. U.S. Dep. Int., Natl. Park Service, Wash., D.C. 90 p.

COOPER, W.S. 1913. The climax forest of Isle Royale. Bot. Gaz. 55:1-44, 115-540.

COTTAM, G and J.T. CURTIS. 1956. The use of distance measures in photosociological sampling. Ecology 37:451-461.

HICKIE, P.F. 1936. Isle Royale moose studies. Proc. N. Am. Wildl. Conf. 11:396-398.

HOSKINS, L.W. and P.D. DALKE. 1955. Winter browse on the Pocatello big game range in southern Idaho. J. Wildl. Manage. 19:215-225.

MURIE, A. 1934. The moose of Isle Royale. Misc. Publ. Mus. Zool. Univ. Mich. 25. 44 p.

PIMLOTT, D.H. 1953. Newfoundland moose. Trans. N. Am. Wildl. Conf. 18:563-581.

FIRE MANAGEMENT IN EVERGLADES NATIONAL PARK

William L. Bancroft[1]

INTRODUCTION

Fire and water are natural environmental factors in the Everglades. Egler (1952) expressed the role of fire as follows:

> It is my contention that the herbaceous Everglades and the surrounding pinelands were born in fires; that they can survive only with fires; that they are dying today because of fires.

Alexander and Crook (1973), Craighead (1971), Hofstetter (1973, 1974), and Hofstetter and Parsons (1975) and Robertson (1953, 1971) also discussed the role of fire in the Everglades.

Natural lightning and Indian-caused fires occurred in the past. Parker (1974), in a study of saw grass and tree-island soil profiles, found ash layers--some up to two inches thick. He stated that:

> These buried ash layers indicate ancient, pre-historic times when there were severe droughts that dried the organic soils of the normally wet glades sufficiently to allow the soils themselves to burn as deep as the existing water table.

Before the arrival of European man these fires maintained a pine forest of South Florida slash pine, *Pinus elliottii densa*, by reducing the competition from the tropical hardwood understory. Natural overland flow of water from Lake Okeechobee to the north along with heavy rains in the summer and fall and fire perpetuated the saw grass glades (a march with scattered islands of trees). Wildlife adapted to a regimen of catastrophe--hurricanes, drought, fire, and frost.

The natural role of fire in the Everglades changed after 1900. Drainage for flood control and land development lowered the water levels 5 to 6 feet below historical levels in some areas (Leach et al. 1972) which resulted in a loss of tons of organic soil by subsidence and burning. Tropical hardwood hammocks, pine forest, and saw grass glade communities were destroyed by deep-burning peat fires during the dry season from November through May. Aggressive exotic plants, such as the cajeput, *Melaleuca quinquenervia*, a fire-dependent species from Australia, invaded disturbed cypress and saw grass glade communities. Many acres of pine were lost to lumbering and development.

By the time Everglades National Park was established in 1947 the natural ecosystems had been severely altered. As the outside pressures of development increased it became clear that fire and water had to be managed in order to perpetuate the natural ecosystems of the park.

FIRE ECOLOGY RESEARCH

The first fire ecology study at Everglades National Park was initiated in the early 1950's (Robertson 1953) and indicated that fire is a natural factor in Everglades National Park, without it the fire-dependent vegetation types, the pine forest and Everglades marsh prairie would disappear. This initial study eventually led to a prescribed burning research project for the control of tropical hardwood invasion into the pineland. This was an exception to the National Park Service fire control policy and the first use of prescribed burning by the National Park Service. Prescribed burning proved to be effective in controlling hardwoods and reducing fuel hazards in the pineland.

During the severe drought of 1962 the Shark Valley Fire burned 77,000 acres (31,174 hectares) in the saw grass glades. Fire control efforts were difficult because of the low water table and heavy fuel buildups. Tracked equipment broke down in the pinnacle rock and became stuck in the saw grass glades. Nine years later another severe drought occurred in South Florida. Prescribed burning in the saw grass glades was initiated as an emergency measure to reduce fuel hazards prior to the 1971 drought (Klukas 1972). These severe fire years indicated a strong need for a comprehensive study of fire in south Florida.

Consequently, a fire ecology research study to assess the effects of fire in all fire-dependent vegetation types was started in 1971 by the University of Miami as a part of the South Florida Environmental Project that was brought about by the Jetport environmental crisis. The objective of the study was to quantify the effects of fire in wet prairie, saw grass glades, and pine communities of South Florida.

Hofstetter (1973) concluded that:

> The great diversity of communities suggests that succession has been stopped at different stages. This has resulted from the action of numerous factors. Fire, by its presence or absence, affects essentially every upland and wetland community here. Some communities --for example saw grass glades, wet prairies, saltwater marshes, grasslands, and pine forest--can exist only with periodic fires.
>
> Without occasional fires, saw grass communities accumulate excessive litter and become decadent...to be replaced by other species. Grasslands generally are invaded by woody species and succeed toward hammocks without periodic fires. Periodic burning maintains communities of fire-resistant species by inhibiting the development of fire-sensitive species.

Hofstetter also recommended that Everglades National Park should:

1. Avoid widespread spring and early summer prescription burning because of disturbance to animal reproduction.
2. Permit a fire mosaic to develop by using spot ignitions during prescribed burns.
3. Burn the pineland every three to seven years.

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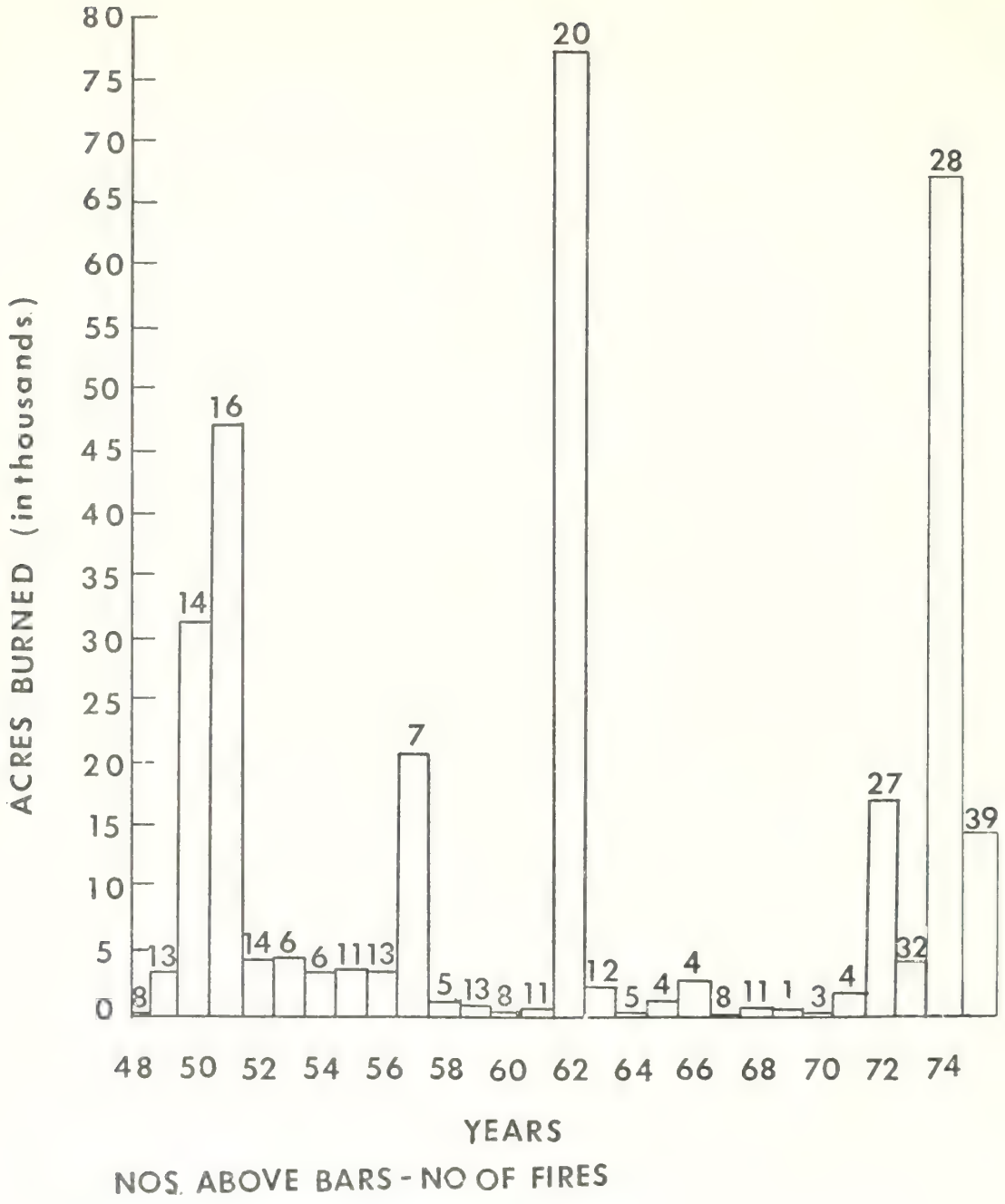

FIGURE 1. Acres burned in Everglades National Park from 1948 to 1976.

4. Attempt to burn areas dominated by graminoids (grass-like plants) every 10 years to control hardwood invasion by using spot ignitions.

As a result of these fire ecology studies and the adoption of a new National Park Service natural fire management policy in 1968 and later revised in 1975 (National Park Service 1975) the fire management program at Everglades National Park began in 1972.

THE FIRE MANAGEMENT PROGRAM

The objective of the fire management program at Everglades National Park is to integrate fire management and water management in order to perpetuate the vegetative mosaics of pine forests, interior saw grass glades, and coastal prairie. This is accomplished by reintroducing fire under prescribed conditions into communities where fire historically played a natural role in their perpetuation. It was recognized that it would be impossible to restore completely natural conditions because of the severe alterations to the natural ecosystems of the park. Allowing only natural lightning fires to burn and suppressing all human-caused fires would not perpetuate the fire-maintained pine forest and saw grass glades. We are therefore attempting to preserve dynamic, changing ecosystems. To accomplish this the following criteria are used:

1. Human-caused and lightning-caused fires, occurring under a favorable prescription and when they meet approved resource management objectives, *may* be allowed to burn in certain zones at certain times.

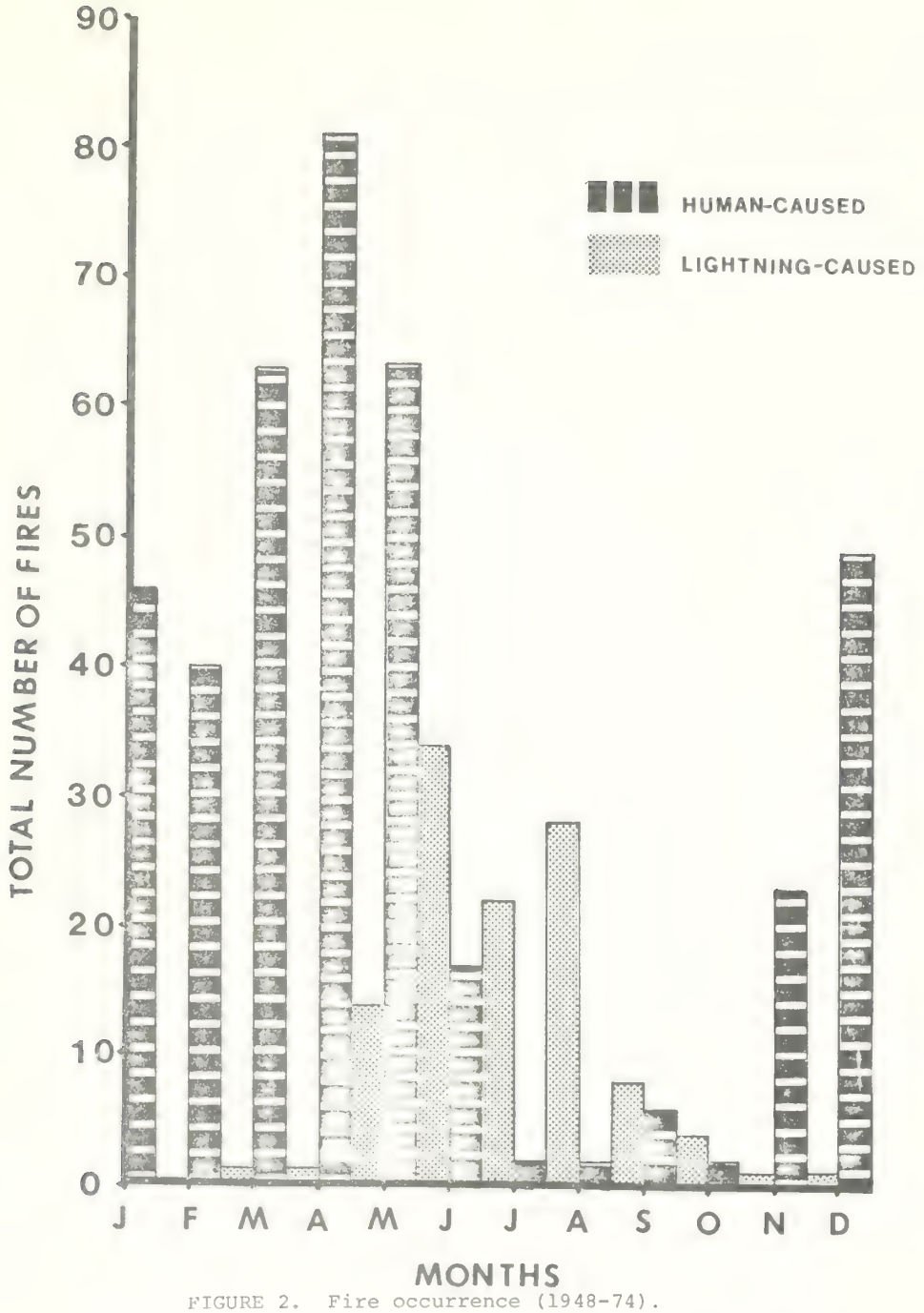

FIGURE 2. Fire occurrence (1948-74).

2. Prescribed burning is conducted when other management fires (a fire that achieves approved resource management objectives) do not occur with enough regularity to maintain the pine forest and saw grass glades.

3. Smoke is a major consideration in the classification of fires. Smoke from fires that will affect metropolitan areas, are classified as wild fires and suppressed.

4. All management fires are contained to predetermined fire management units.

5. All fires that threaten cultural resources, physical facilities, endangered species, or human life; threaten to escape from the park; or otherwise do not meet the prescription are classified as wildfires and suppressed.

Fire History

Some 343 recorded fires have burned a total of 315,046 acres (127,549 hectares) since the park was established in 1947 to 1976. Human-caused

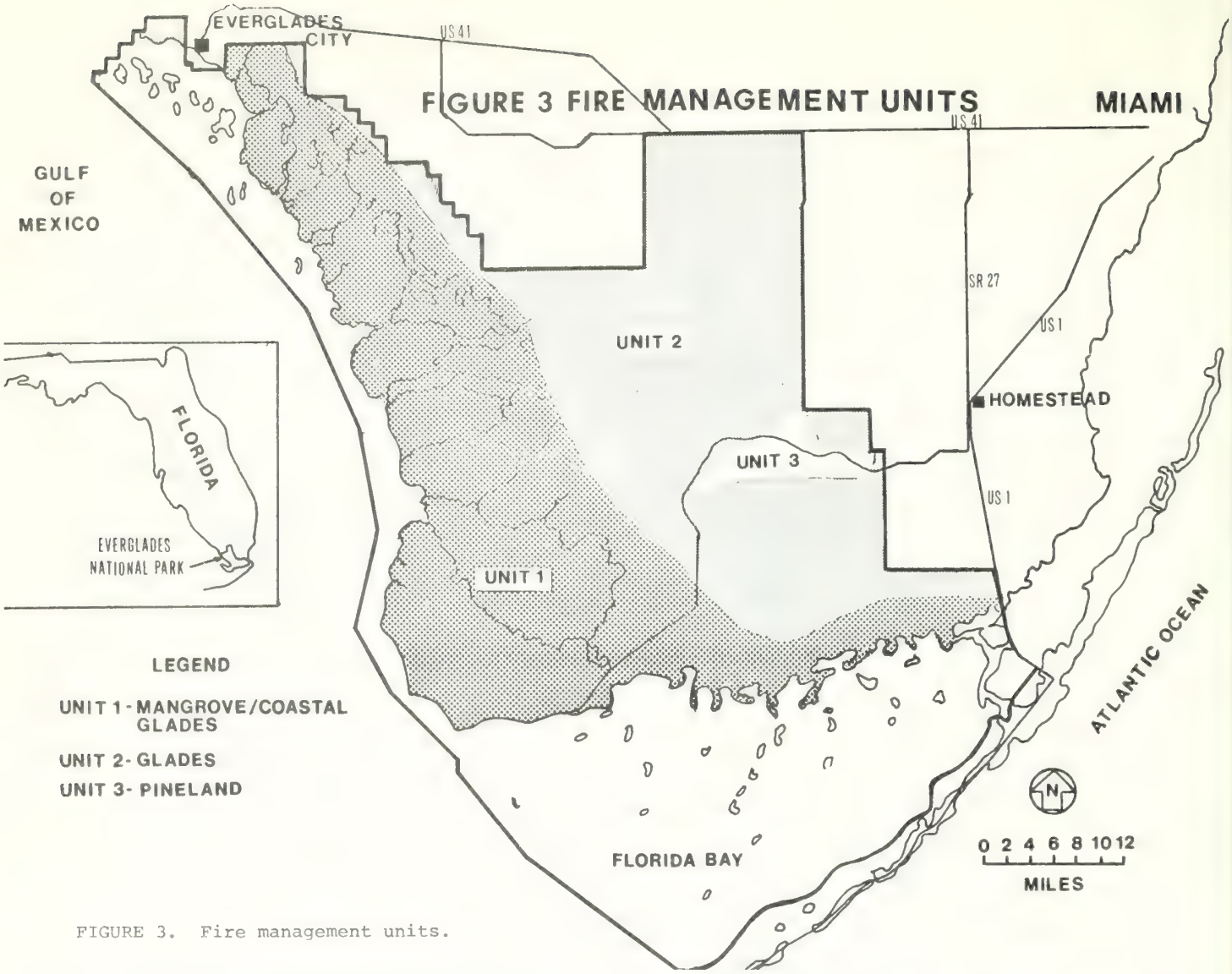

FIGURE 3. Fire management units.

fires accounted for 200 fires (238,961 acres or 96,745 hectares), whereas lightning caused 143 fires (76,085 acres or 30,804 hectares). Fire suppression was successful prior to the fire management program except during severe droughts in 1950-51, 1957, and 1962 (Fig. 1).

Human-caused fires occurred mostly during the dry season from November through April, whereas lightning-caused fires occurred during the wet season from May through October (Fig. 2).

Fire Management Units

Three fire management units (Fig. 3) comprising 705,078 acres (285,456 hectares) were designated as follows:

1. *Mangrove/Coastal Glades* (328,437 acres or 132,966 hectares) . The main fire types in this unit are the hundreds of small estuarine marshes of saw grass, *Cladium jamaicense*, cord grass, *Spartina bakeri*, and black rush, *Juncus roemarianus*, and the coastal prairie on well-drained soils on Cape Sable.

2. *Everglades Marsh Prairie* (356,811 acres or 144,458 hectares). Unit 2 is a large shallow freshwater marsh impounded behind the mangroves. Freshwater marl prairie, dominated by muhly grass, *Muhlenbergia filipes*, saw grass, *Cladium jamaicense*, and *Schizachyrium rhizomatum* is the most abundant community. Saw grass that once covered much of the unit is now less common because of drainage and fire (Craighead 1971). Tree islands (bayheads and tropical hardwood hammocks are scattered throughout. Most of the fires occur in this unit during the dry season.

3. *Pineland* (19,840 acres or 8,032 hectares). This unit is a fire-maintained pine forest of South Florida slash pine, *Pinus elliottii densa*. The forest once occupied most of the limestone ridge along the southeastern coast of Florida. Some 125 tropical hardwood hammocks are found scattered on elevated sites within the pineland. Nearly 100 endemic shrubby and herbaceous species occur in the understory and are dependent on fire for their existence.

Fire Management Actions--Depending on the fire prescription, three fire management actions--suppression, containment, or observation--may be taken when a fire starts. Suppression is the direct attack on a wildfire. Suppression techniques are chosen that will do the least amount of damage to the resources.

Containment is the confinement of a wildfire by direct or indirect means to a predetermined area within a fire management unit. Containment is a gray zone between full suppression and observation. Techniques include backfiring, burning-out and spot firing with Delayed Action Ignition Devices (DAID's) (Sackett 1974) from a helicopter to reduce fuel around tropical hardwood hammocks, to protect

TABLE 1. Fire management prescriptions, Everglades National Park.

Fire Management Unit	Fire Management Actions		
	Suppression	Containment	Observation
Unit 1 (Mangrove Coastal Glades)	Protect Structures	Protect Structures	Season Long
Unit 2 (Everglades Marsh)	-At Park Boundary -Special Biological Sites -DI 600 -SMH 67% -SW-W Winds near Park Boundary -W.L. 1.8ft (.5m) M.S.L. at NP-44	-Fires Approaching Park Boundary -Special Biological Sites -DI 500-600 -SMH 67%-100% -W.L. .8ft (.2m)-1.8ft (.5m) M.S.L. at NP-44	DI 500 SMH 100% W.L. 1.8ft (.5m) M.S.L. at NP44
Unit 3 (Pineland)	-When physical facilities or cultural resources are threatened -DI 550 -SMH 67% -SW-W winds -W.L. .8ft (.2m) M.S.L. at NP-44	-DI 500-550 -SMH 67%-82% W.L. .8ft (.2m)-1.8ft (.5m) M.S.L. at NP-44	DI 500 SMH 82% W.L. 1.8ft (.5m) M.S.L. at NP-44

DI = Drought Index
SMH = Soil Moisture in Hammocks
W.L. = Water Level
M.S.L. = Mean Sea Level

structures, and to contain head fires. No suppression action is taken on observation fires.

One or all fire management actions may be taken on a fire depending on the prescription for the area in which the fire occurs. A Drought Condition Report lists the fire prescription for each fire management unit and the fire management action(s) to be taken should a fire occur. When a fire is discovered it will be declared either a management fire (observation action only) and allowed to burn or a wildfire (suppression or containment). Table 1 shows the fire management prescriptions and actions used in Everglades National Park.

Fire Management Strategies

Fire Prescriptions--Fires that occur during the wet season have little serious effect since almost all of the park is flooded. During the dry season fires become severe when the water level drops several feet below the surface and can destroy tropical hardwood hammocks and saw grass glade communities by burning the peat soils. Craighead (1971, 1974) reported that peat soils in tropical hardwood hammocks burn when the moisture content is less than 30-35 percent. Fire prescriptions [a written statement defining the objectives to be attained, the conditions under which a fire will be allowed to burn, and the limit of the geographic area to be covered (National Park Service 1976)] were developed which consider the importance of soil moisture in determining fire effects. The action taken on a fire depends on these prescriptions.

The two most important parameters of the fire prescriptions are drought index (Keetch and Byram 1968) and soil moisture; other parameters include fire location, water level, and smoke. Drought index is:

> A number representing the net effect of evapotranspiration and precipitation in producing accumulative moisture deficiency in deep duff or upper soil layers; . . . it is a quantity that relates to the flammability of organic material in the ground.

When the index reaches about 600 and the soil moisture is about 67 percent oven dry wt. or less, peat soils will burn. Drought, soil moisture, and water level are determined at 16 tropical hardwood hammock sites during the dry season.

Prescribed Burning

Prescribed burning is an important part of the fire management program at Everglades National Park. About 10,000 acres (4,049 hectares) are burned each year. The objectives of the prescribed burning program are to:

1. Control hardwood invasion into the pineland by prescribed burning every 3 to 7 years.

2. Reduce fuel accumulations along the park boundary in order to prevent severe drought fires from entering the park or observation fires from leaving the park.

3. Revitalize deteriorating saw grass communities where the fire frequency has been exceeded.

4. Control exotic plants, such as Australian pine, *Casuarina* spp. to lessen their impact on the park resources.

5. Manage for early stages of plant succession on recently acquired farmlands in the park.

TABLE 2. Total number, size and cost of wildfires and management fires in Everglades National Park from 1972 to 1976.

Type of Fire	Number of Fires	Acres (Hectares) Burned	Cost
Wildfires	21	79,052 (32,005)	$70,631
Management Fires			
Natural Fires	76	14,980 (6,065)	$ 7,539
Human-Caused Fires	29	6,994 (2,832)	$ 1,852
Prescribed Burns	177	40,001 (16,195)	$54,528
Totals (Management Fires)	282	61,975 (25,092)	$63,919

Summary of the Fire Management Program

Wildfires--Table 2 shows the number, size and cost of all wildfires and management fires from 1972 to 1976. All of the wildfires were human-caused and occurred during the dry season. Seventeen fires burned 76,184 acres (30,844 hectares) in unit 2, whereas four fires burned 2,868 acres (1,161 hectares) in unit 3. Six of these wildfires (61,470 acres or 24,887 hectares) occurred during the severe 1974 drought.

Management Fires

Lightning Fires--All lightning fires were allowed to burn. They all occurred during the wet season and were extinguished by the third day either by rain that accompanied the thunderstorm or high humidity. The largest lightning fire burned 2,960 acres (1,198 hectares) in an estuarine marsh in June 1975.

Human-caused Fires--Twenty-nine human-caused fires were allowed to burn. These fires were in acceptable prescription and met approved resource management objectives. Suppression of these fires would have resulted in unacceptable loss to the resources.

Prescribed Burns--From 1958, when the first prescribed burn occurred in the pineland, to 1972, 102 burns (28,502 acres or 11,540 hectares) mostly in pineland were conducted. Since 1972, 177 prescribed burns (40,001 acres or 16,195 hectares) have occurred. The average cost was about $1.36 per acre ($3.36 per hectare).

CONCLUSION

The fire management program at Everglades National Park should continue to expand. With the addition of a fire ecology research program directed by a new fire ecologist the fire management program will be complete. This research program will assess the short and long term impacts of fire on the ecosystems of the park, determine the changing role of fire in relation to water levels, exotic plants, vegetation and wildlife, and make recommendations to park management concerning the best methods for reaching the fire management objectives. The program will change as we acquire more knowledge about fire and as the ecosystems change. With less water, we will not be able to allow fires to burn except under very wet conditions. More prescribed burning during safe conditions may be needed to keep fuels at low levels to lessen the fire damage during severe drought years. With the acquisition and future management of the Big Cypress National Freshwater Preserve fire management will soon become a regional program of great significance to the National Park Service. By intelligently managing fire and water that generated this unique environment, Everglades National Park and the Big Cypress Freshwater National Preserve will be perpetuated for future generations.

LITERATURE CITED

ALEXANDER, T.R. and A.G. CROOK. 1973. Recent and Long-Term Vegetational Changes and Patterns in South Florida. Report submitted May, 1973, to U.S. Department of the Interior on Contract, Department of the Interior, National Park Service, 14-10-9-900-358.

CRAIGHEAD, F.C., SR. 1971. The Trees of South Florida, Vol. 1. The Natural Environments and Their Succession. University of Miami Press, Coral Gables, Florida, 212 p.

CRAIGHEAD, F.C., SR. 1974. Hammocks of South Florida, pp. 53-60. *In* Memoir, Miami Geological Society.

EGLER, F.E. 1952. Southeast Saline Everglades Vegetation, Florida, and its Management. Vegetatio Acta Geobotanic 3:213-265.

HOFSTETTER, R.H. 1973. Fire in the Ecosystem, and ecological study of the effects of fire on the wet prairie, saw grass glades and pineland communities of South Florida. (Part I, Final report on Contract No. 14-10-9-900-355 between the NPS and the University of Miami, Miami, Florida.)

HOFSTETTER, R.H. 1974. The Effect of Fire on the Pineland and Saw Grass Communities of Southern Florida, pp. 201-212. *In* Memoir, Miami Geological Society.

HOFSTETTER, R.H. and F. PARSONS. 1975. Fire in the Ecosystem, and ecological study of the effects of fire on the wet prairie, saw grass glades and pineland communities of South Florida. (Part II, Final Report on Contract No. 14-10-9-900-355 between the NPS and the University of Miami, Miami, Florida.)

KEETCH, J.M. and G.M. Byram. 1968. A Drought Index for Forest Fire Control. Southeast Forest Exp. Station, U.S. Department of Agriculture Forest Service Res. Pap. SE-38, 32 p.

KLUKAS, R.W. 1972. Control Burn Activities in Everglades National Park. Tall Timbers Fire Ecology Conference, No. 12, pp. 397-425.

LEACH, S.D., H. Klein, and E.R. HAMPTON. 1972. Hydrologic effects on water control and management of southeastern Florida; U.S. Geological Survey, Report of Investigations No. 60, Tallahassee, Florida, 115 p.

NATIONAL PARK SERVICE. 1975. Management policies. Washington, D.C., U.S. Department of the Interior, National Park Service.

NATIONAL PARK SERVICE. 1976. Fire Management, U.S. Department of the Interior, National Park Service. Staff Directive 76-12, pp. 1-12.

PARKER, G.G. 1974. Hydrology of the Pre-Drainage System of the Everglades in Southern Florida. *In* Memoir 2: Miami Geological Society, pp. 18-27.

ROBERTSON, W.B., JR. 1953. A survey of the effects of fire in the Everglades National Park. Mimeo report, National Park Service, 169 p.

ROBERTSON, W.B., JR. 1971. A quick look at natural history biogeography and biopolitics in South Florida. Talk at Am. Inst. of Biological Sciences, Second National Biological Congress in Miami, Florida, mimeo 15 p.

SACKETT, Stephen S. 1975. Airborne Igniters for Prescribed Burning. Fire Management Vol. 36(2): 12-13.

PATTERNS OF SOIL EROSION AND VEGETATION DAMAGE ASSOCIATED WITH TRAILS AND CAMPSITES IN GREAT SMOKY MOUNTAINS NATIONAL PARK

Matthew G. Hickler and Susan Power Bratton[1]

The Great Smoky Mountains National Park has the distinction of being the most visited national park in the country. Over eight million visitor days were recorded in the 1975 season, and visitation has been continually increasing over the past several years. Backcountry use has been rising at a disproportionate rate, putting increased stress on the park's backcountry resources. This study was designed, in part, to provide quantitative information on the physical condition of trails and campsites and provide data on which to base future monitoring. Other aims of the study include:

1. Delineating sections of trail which have severe erosion of extensive muddy areas.

2. Locating trails which can tolerate more impact, those which are at carrying capacity, and those which are above carrying capacity.

3. Determining which trails, with minor changes in maintenance, could absorb more traffic.

4. Locating trails which are eroding because of use by horses.

5. Determining if trail conditions vary from one section of the park to another.

6. Determining how trail conditions are related to environmental variables such as forest type, trail slope and elevation.

7. Locating areas where the park should be encouraging use and areas where use should be discouraged.

8. Locating areas where additions might be made in the trail system or where rerouting or removing sections of trail might be advantageous.

9. Quantifying damage associated with campsites.

10. Identifying campsites which are above carrying capacity and those which are below or at carrying capacity.

11. Locating illegal campsites and studying patterns of illegal camping in the park.

12. Determining the impact of campsites on the native flora.

13. Estimating from patterns of illegal camping in the park where people would be likely to camp under a zone camping system.

14. Locating areas where new campsites should be established.

15. Locating areas where poor trail conditions indicate that no new sites should be established or that old sites should be removed.

METHODS

Data were collected on all the maintained trails in the park and on a number of manways. Sample sites were located at 1/3 mile intervals and marked on 7.5 minute topographic maps. Each sample consisted of a series of measurements for slope of trail, aspect of trail, slope of environment, aspect of environment, elevation, total width of the trail cut, width of rock, width of soil, width of undisturbed leaf litter and depth. Estimates of percent of mud, rut, bare rock, horse plow, foot plow, exposed roots, hog rooting, and bank erosion were made for each 1/3 mile section. All mud holes and badly eroded spots were measured for length, width and depth.

Trails were typed and placed in classes on the basis of past history and maintenance status. The information recorded included:

1. Whether the trail was cut to foot width or ran along old settler roads, jeep trails or logging railroad grades.

2. Whether the trail was a manway or a maintained trail.

3. The type of use for which the trail was designated (foot only, foot-horse, or horse only).

Forest and understory were typed at the position of each sample. This was done visually on the basis of species composition and dominance. Four major forest types, each with several subdivisions, were recognized (Table 1). An early successional type which consisted of all areas with an open canopy was also recognized. The successional status of the forest was noted and recorded as early successional, second growth, mature, or virgin.

At each sample point the section of trail just covered was given an erosion rating and an overall rating on a scale of 1-5. A "1" indicates the least damage and a "5" the most. Guidelines were established concerning maximum tread widths and amount of erosion which would be allowed in each class. It was hoped that these guidelines would result in an objective classification and provide consistency between the various investigators who collected field data. The standards were loose enough, however, that some personal bias did enter into the ratings.

To help overcome this problem a computer program was used to generate a more objective rating based on actual figures. This was done by developing a set of arbitrary standards on the maximum tread widths and amounts of mud, rut, bank erosion, etc., that would be allowed in each class. The computer sorted for these and generated an objective rating accordingly.

No attempt has been made to quantify how much trails are being used. Some little-used trails have been rated as poor because of erosion problems unrelated to use, and, conversely, some heavily used trails have been rated in average or good condition.

For analysis, the park was divided into sixteen sections on the basis of general access and

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TABLE 1. Forest type codes.

1. Spruce-Fir-(Yellow birch)
   - 1-1 Spruce-Fir-(Yellow birch)
   - 1-2 Spruce-Fir-Hardwood or Hemlock
   - 1-3 Yellow birch
   - 1-4 Laurel-Heath bald

2. Northern Hardwoods
   - 2-1 Beech Gap
   - 2-2 Mixed Northern Hardwoods
   - 2-3 Successional (yellow birch, fire-cherry, red maple, etc.)

3. Mesic Types
   - 3-1 Mixed Cove Hardwoods
   - 3-2 Hemlock-Hardwood Cove
   - 3-3 Mesic Hardwood Flats
   - 3-4 Successional Cove (tulip tree, silverbell, fire-cherry, red maple, black locust, etc.)
   - 3-5 Mixed Sub-mesic Hardwoods (tulip tree, silverbell, hemlock and other cove elements in association with more xeric hardwoods, such as oaks, and pines)
   - 3-6 Tulip Tree Second Growth
   - 3-7 Hemlock Cove

4. Xeric Types
   - 4-1 Mixed Sub-xeric Hardwoods
   - 4-2 Mixed Xeric Hardwoods
   - 4-3 White Oak
   - 4-4 Mixed Oak-Pine (including Maple-Pine, Sourwood-Pine, etc.)
   - 4-5 Mixed Xeric Pines
   - 4-6 White Pine

5. Balds, Burn Scars, Pastures
   - 5-1 Grassy Bald
   - 5-2 Burn Scar
   - 5-3 Pasture and Old Field
   - 5-4 Early Successional (fire cherry, service berry, hawthorn, etc.)
   - 5-5 Laurel and Other Heaths

a general knowledge of visitor use patterns. Within each section, the trails were divided at major nodes or intersections and numbered. The internodes became the basic trail unit.

All campsites encountered, both legal and illegal, were measured and their locations were marked on 7½ minute topographic maps. A great deal of information was recorded for each site including: total distribution, position and condition of water source, drainage, topographic position, presence of exotic plants, slope and aspect, number of fire pits, amount and distribution of trash, and developments such as hitch racks, shelter frames, and pit toilets.

The total distribution of the site was recorded as a series of concentric measurements. These included the area of bare soil, leaf litter, trampled vegetation, trash, tree damage, and firewood clearing. All mud holes and badly eroded spots were measured for length, width and depth.

The data were coded and punched on computer cards. Analysis was by standard statistical programs on an IBM 360 computer.

RESULTS

The data analysis for this study is not yet complete and the final results should be available as an Uplands Field Research Laboratory Management Report in the spring of 1977. We present here some examples of how the data can be used to provide information on trail erosion in the park.

Various environmental conditions can be correlated to erosion class. Forest type, for instance, is not only related to the amount of erosion but also to the type of erosion (Tables 2 and 3). Trails in early successional types have the highest erosion ratings, primarily because of a strong tendency to rut. Exposed rock is also extensive, but in all other respects these trails are in better than average condition.

Trails in spruce-fir have better ratings than those in early successional areas, but their erosion problems are exceedingly diverse. These trails are worse than average for all types of erosion which were measured and have the most extensive erosion in all categories except percent of rut. The northern hardwood and mesic types fall close to one another in terms of computer erosion ratings but have slightly different problems. Trails in northern hardwoods have more mud and exposed roots, and those in mesic types are more extensively rutted and have more exposed rock. Differences also exist in the amount of mud and bank erosion.

Trails in xeric forest types have the least erosion. They are consistently better than average in all types of erosion except bank erosion and are exceeded in this area only by trails in spruce-fir. These trails are more heavily rutted than those in northern hardwoods or mesic types but are still better than average for all types in this respect.

A comparison between different sections of the park shows that trail conditions vary significantly from one area to another (Table 4). An area such as Deep Creek can be compared to an area such as Mt LeConte, perhaps the most heavily used section of the park. The trails are not only wider in the LeConte section, but the tread (exposed soil and rock) is a much greater percentage of the trail cut. In the LeConte section the average recorded depth is over nine times greater and the percentage of rut is seven times greater.

A similar comparison can be made between the Boundary trail and the Appalachian Trail, both of which are long distance trails running in an east-west direction. The Appalachian Trail has more campsites and more traffic. The Appalachian Trail has about 2½ times the tread width of the Boundary Trail and over ten times the percentage of exposed roots. These differences are due, at least in part, to differences in the amount and type of use the trails receive. Variations in the average grades of the trails and in the relative proportions of the various forest types may also be a factor.

The campsite data have not been completely analyzed but several patterns can be drawn from the figures available. First, although illegal sites are usually smaller than legal sites, they greatly outnumber legal sites. (Figures 1 and 2) Illegal camping is not necessarily related to any lack of legal camping facilities as illegal sites are frequently close to legal sites. In a few cases the illegal sites are in the same size range as the nearby legal sites (see Site 1 and Site 4 in Figure 2). Some areas of the park, such as Mt LeConte, have more illegal camping than others (compare Figures 1 and 2). Illegal sites are largely found along creek flats and in gaps on ridge tops.

The campsite data also indicate there are differences in the type of disturbance associated with different types of sites. Shelters, for

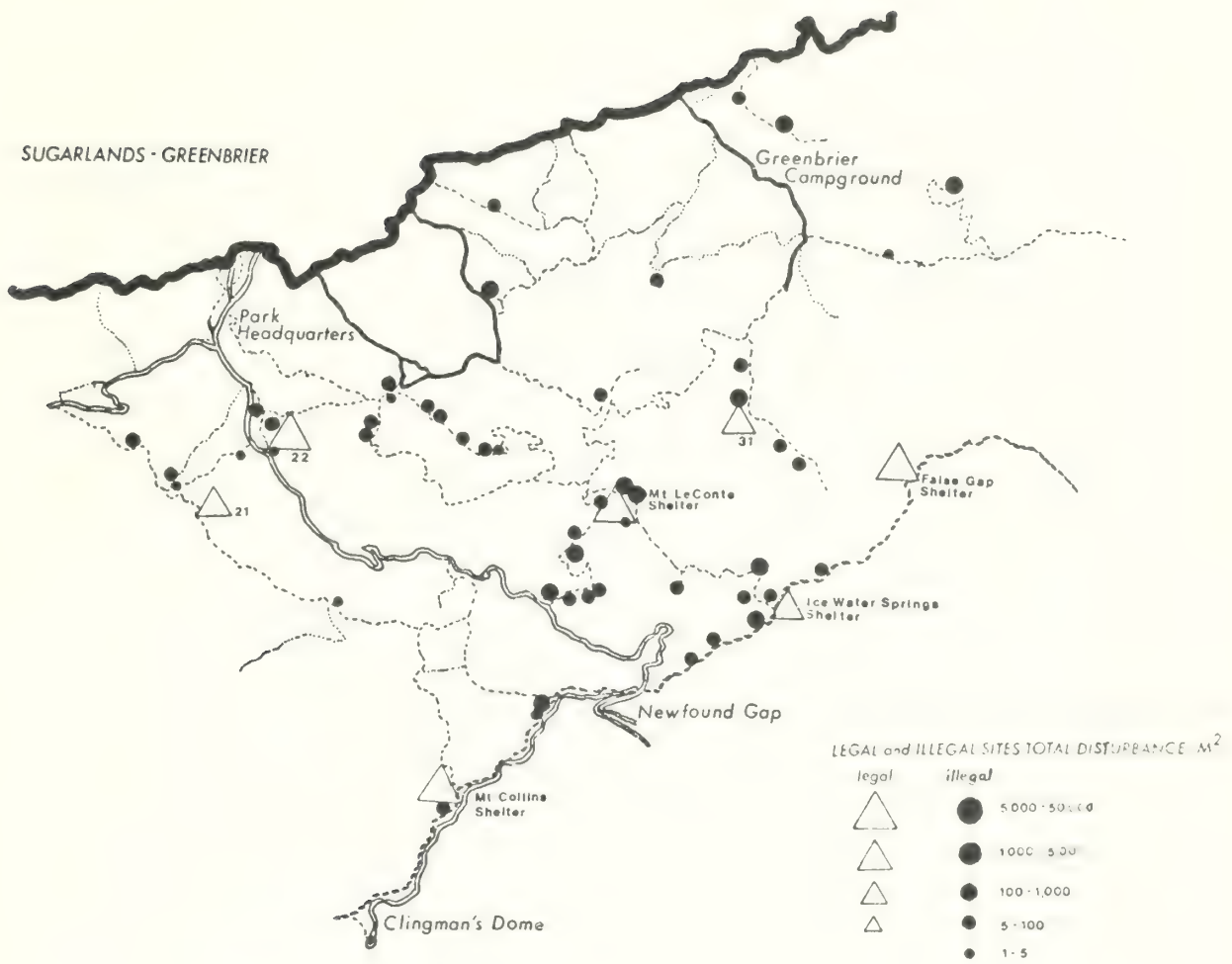

FIGURE 1. A comparison of legal and illegal campsites for the LeConte section. Illegal sites far outnumber legal sites but are usuallt smaller.

TABLE 2. Observed and expected values in a cell chi-square table of computer erosion rating vs. forest type.

Forest type	Computer Erosion Rating 1-2	3	4-5	Totals
Spruce-fir	126.00	112.00	99.00	337.00
	154.85	99.65	82.56	337.00
	5.38	1.53	3.30	10.21
Northern hardwoods	124.00	50.00	42.00	216.00
	118.08	58.97	41.08	216.00
	0.30	1.36	0.02	1.68
Cove	433.00	241.00	165.00	839.00
	457.28	231.54	172.93	839.00
	1.29	0.39	0.36	2.04
Oak-pine	570.00	211.00	152.00	933.00
	511.16	231.05	161.67	933.00
	6.77	1.74	0.58	9.09
Early successional	30.00	14.00	17.00	61.00
	30.27	17.38	12.30	61.00
	0.00	0.66	1.80	2.46
TOTALS	1,283.00	628.00	475.00	2.387.00
	1.283.00	628.00	475.00	2,387.00
	13.74	5.68	6.06	25.48

The observed values are listed first, then the expected values and the chi-square value.

Total chi-square = 25.48 with 8 degrees of freedom; p = 0.002.

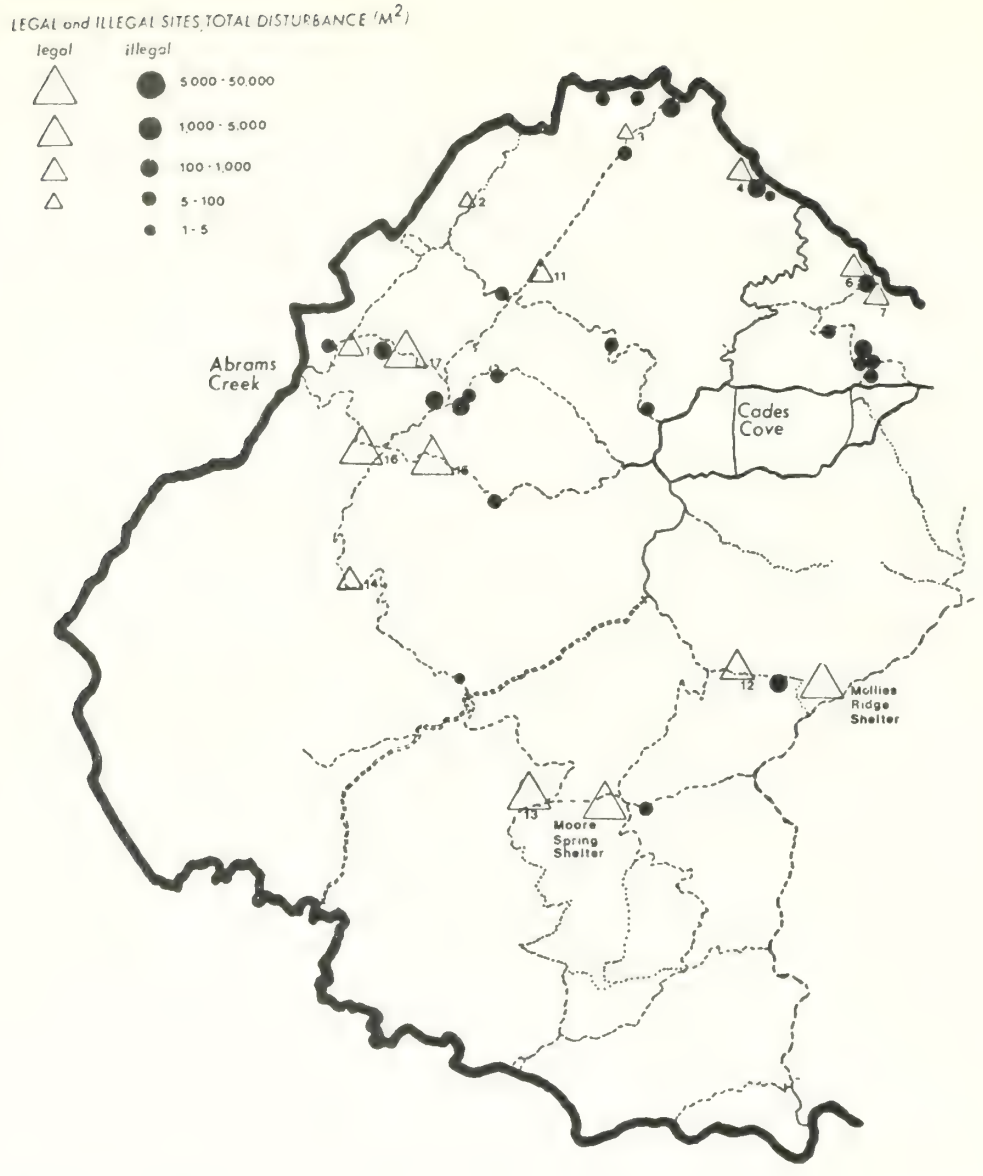

FIGURE 2. A comparison of legal and illegal campsites for the Cades Cove section. Illegal sites are often very near legal sites.

TABLE 3. Forest type vs. trail deterioration for maintained trails.

Forest type	Number of sections	Average % mud	% damage % rut	% exposed rock	% exposed roots	% bank erosion	Average erosion rating
Spruce-fir	310	8.2	15.5	37.0	15.2	7.4	3.1
Northern hardwoods	174	5.6	5.2	9.8	10.0	2.4	2.6
Mesic types	670	4.9	8.0	13.0	8.2	4.2	2.7
Xeric types	709	4.9	8.5	7.3	3.9	7.1	2.4
Early successional	41	5.4	25.0	17.0	3.6	1.7	3.6
AVERAGE FOR ALL TYPES	1904	5.8	12.4	16.8	8.2	4.6	3.1

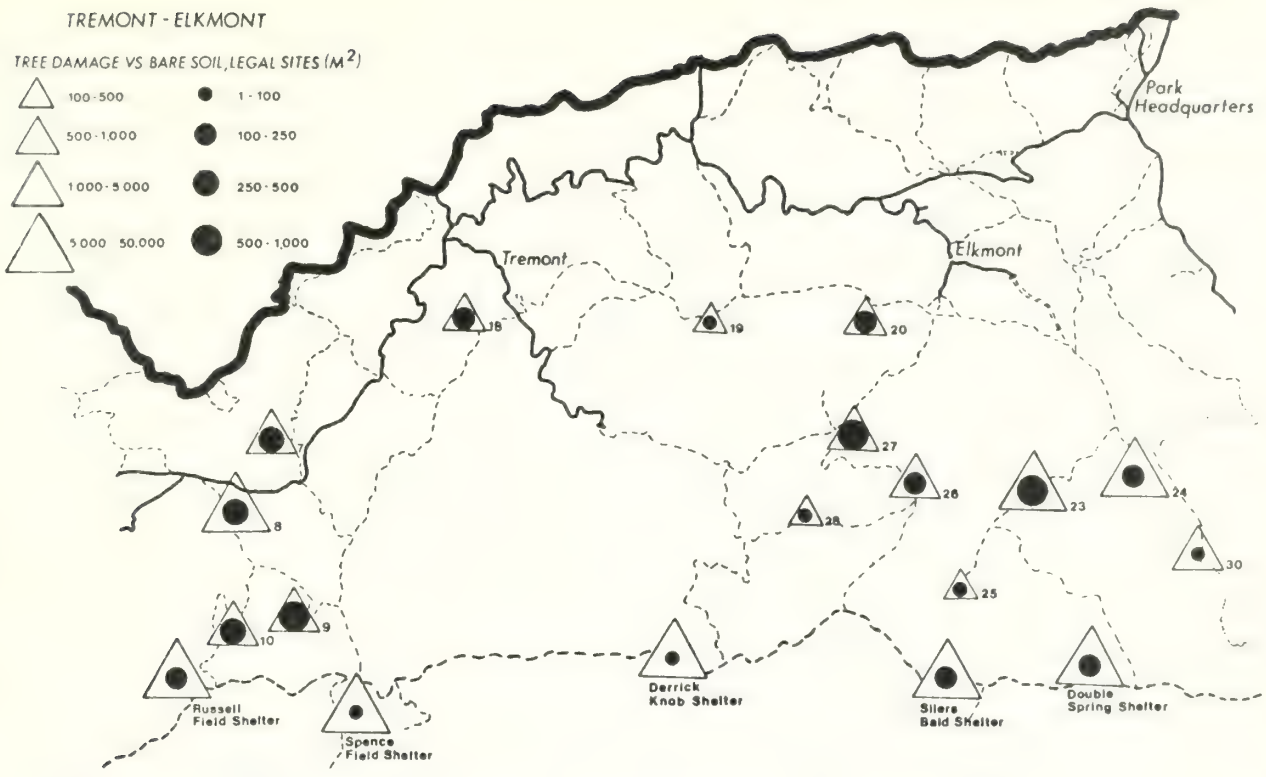

FIGURE 3. A comparison of the amount of tree damage and fire-wood gathering to bare soil for legal sites only. Shelters are named and campsites are numbered.

TABLE 4. Average slope and erosion measurements for the maintained trails in selected sections of Great Smoky Mountains National Park.

Section	Width cm	Width tread cm	Tread %	Depth cm	Trail slope°	Environ slope°	% mud	% rut	% roots	Computer erosion rating
Deep Creek (section 12)	96.0	40.6	42	.9	3.4	17.8	3.5	2.7	3.8	2.1
Boundary Trail (section 8)	107.8	42.6	40	2.8	3.7	22.7	4.1	6.8	1.1	2.2
Appalachian Trail (section 1)	123.2	104.1	84	7.8	4.7	15.2	12.9	12.9	12.6	3.0
Mt. LeConte (section 6)	145.5	111.5	77	8.5	6.2	18.9	9.0	19.4	15.4	3.1

instance, tend to have a greater total distribution of disturbance but less bare soil than sites without shelters (Figure 3). Firewood gathering and cutting is usually the most extensive type of damage at the largest sites.

Some sites are located in areas with rich herbaceous understories which are very sensitive to trampling. Where topography and shrubby vegetation are not limiting, as is common on creek flats, expansion of sites often occurs. Campers not wanting to pitch tents on bare soil move to the periphery of the site and camp in vegetated areas.

MANAGEMENT APPLICATIONS

The most important aspect of management oriented research is its application to park problems and park planning. Data from this study, for instance, have already been used in an environmental analysis of the impact of a proposed road on the Deep Creek section of the park. The analysis includes descriptions and erosion measurements for each of the major trails in the area near the proposed road. General trail condition for the Deep Creek section was compared to other sections of the park. The data can be used to predict potential problem trails or trail sections should the road be built and visitor impact on the trails increase.

Since environmental variables are correlated to the type and amount of trail erosion, the data can be used to describe the types of trails most likely to erode under increased impact. If the construction of new trails becomes necessary, the relative risks of putting trails in different areas can be evaluated. Display maps which show the trails by erosion class are already available. With proper interpretation, the width, depth and

erosion data can be used to classify trails in terms of physical carrying capacity. Sections of the park where the trails are well above carrying capacity are being identified so that future planning can determine where visitor use should be encouraged or discouraged.

The campsite data are being used to locate areas of extensive damage around legal sites and areas where camping could well be increased. Trails with severe illegal camping problems can be easily delinated on maps such as Figures 1 and 2. Some of these areas need greater patrol or increased maintenance.

The data can be used to evaluate present camping regulations and to predict the effects of alternate camping schemes. Since the impact of firewood gathering in different areas of the park has been quantified, park management can now decide if this activity needs to be restricted in any sections of the park. Park management is also interested in the advantages and disadvantages of shelters at backcountry campsites. Present data indicate that firewood gathering and tree damage are very extensive around shelters, but that shelters usually have less bare soil than open campsites of similar dimensions. If shelters are removed and replaced with open campsites, the number of visitors using the site should be reduced below shelter levels to prevent an increase in the area of bare soil and trampled vegetation.

It has recently been suggested that zone camping be established for all or part of the park. If one assumes that present legal and illegal sites will be frequently used by campers under the zone system, then it is possible to map those areas liable to be damaged by users selecting their own sites. In the Great Smokies, gaps and creek flats are the areas most likely to be chosen and the sites are likely to be clustered in certain topographic situations. Many of the creek flats and some of the gaps in northern hardwood forests have sensitive herbaceous understories and should not be subjected to trampling. Zone camping on an all park basis, therefore, is probably not practical.

The trail and campsite data now available can be used to establish practical stands for determining when a trail or campsite is overused. At present, campsite condition is not subject to review and sites are not necessarily closed if they begin to deteriorate. Quantitative data on campsite size and condition allows park management to decide what the carrying capacity for the sites should be and whether an increase or a decrease in visitor use is appropriate.

CULTURAL INFLUENCES ON SUBALPINE AND ALPINE MEADOW VEGETATION IN YOSEMITE NATIONAL PARK

Daniel O. Holmes[1]

INTRODUCTION

Five human-related activities have affected the high meadows in Yosemite: burning, hunting, grazing, hiking, and horseback riding. Their effects on plant cover and species composition, and the relationship of these activities to the invasion of the meadows by lodgepole pine (*Pinus Murrayana* Grev. and Balf.) have been of concern to many mountain travelers and scientists (Boche 1974; Bradley 1911; Briggs 1966; Russell 1927; Sharsmith 1961; Sumner 1947). A brief review of some of the characteristics of these meadows precedes a discussion of the activity effects.

THE MEADOWS

The high mountain meadows in Yosemite National Park are generally above 2400 m (8000 ft) elevation and within the High Sierra (LeConte 1907:5), a region designated by the National Park Service as consisting of the lodgepole-subalpine and alpine ecosystems (Department of Interior 1975). The meadows, which range in length from a few meters to several kilometers, are located on ridgetops as well as in canyon bottoms, where snowbanks, drainages, or springs provide a good supply of moisture (Muir 1961:100-111). Meadows are usually adjacent to lakes and streams. Billings and Mooney (1968:489) characterized the environmental factors controlling the distribution of meadows above timberline as "topographic exposure and distribution of snow and meltwater superimposed upon geographic substratum patterns." Holmes and Dobson (1976:17-18) estimated that out of the 165,000 ha (407,000 ac) of park land in the lodgepole-subalpine and alpine ecosystems, 5.6% or 9200 ha (22,700 ac) are meadows.

Wood (1975a) investigated the origins of the upper meadows of the Sierra. He showed that many meadow sites were previously occupied by forests and that the ages of the meadows may coincide with neoglaciation in the Sierra at 2500 B.P. and 1200 B.P. (Wood 1975a:107). Since the rate of accumulation of meadow topsoil has equaled only 2.3 cm per century, the topsoil in many meadows is a veneer 50 cm or less in depth (Wood 1975a: 103).

Three excellent articles explain much of what is known about Sierra alpine plant physiology and ecology; these were written by Tranquillini (1964), Billings and Mooney (1968), and Chabot and Billings (1972). The ranges of most of the low-growing, meadow plants in the lodgepole-subalpine ecosystems extend into the alpine zone.

The meadow plants are almost exclusively perennials, a characteristic which allows very rapid growth in the early spring and does not make the plant's survival dependent upon successful annual seed production (Chabot and Billings 1972: 194). Growth of the meadow plants begins rapidly as the snow melts off the ground, and the meadows usually stay entirely green into August. Although the peak blooming period is in July, blooming varies widely with microclimate, altitude, and plant species (Dobson 1975).

The rate of natural succession in meadows decreases with increasing altitude in the Sierra Nevada (Sharsmith 1959). Sharsmith (1959:8) concluded that "owing to the rather progressive diminution in the number of species with increasing altitude, the stages of succession tend to become correspondingly fewer and more simplified."

References to the productivity of Sierra meadows were reviewed by Wood (1975a:19-21). Low productivity and exposure to wind result in a very low accumulation of dead plant material. This is one factor that makes natural fire unlikely in the upper meadows. Reynolds (1959:59-91) also attributed the rarity of natural fires in the high mountain meadows to topographical and other ecological factors. In addition, the lodgepole forests, which border most of the meadows, do not usually produce enough fuel to sustain a surface fire which could then spread into a meadow (Reynolds 1959:117). Meadow fires are even more difficult to envision, whether they are natural or set by humans, considering that the dry meadows are typified by sparse, tussocky herbage and that the wet meadows generally remain damp into the fall.

BURNING

Deliberate burning in the High Sierra has been attributed to both the Miwok Indians and the sheep herders. While Indian occupation of the higher elevations in the summer and fall is well documented and supported by an abundance of archaeological sites, complete documentation of their specific activities is lacking. Gibbens and Heady (1964:2) and Reynolds (1959:120-123, 140), referring in part to an earlier work by Bennyhoff (1956:16-17, 19), proposed that the Yosemite Miwoks burned the high meadows to drive game. Reynolds (1959:121-123) suggested that burning by the Indians must have accounted for the early absence of small lodgepole pines in the meadows. Reynolds' (1959:121) unfortunate reliance upon what is possibly a misdated photograph in documenting the early absence of small invading trees prior to sheep grazing, raises a question as to the validity of his basic assumption. The photograph may not predate the sheep grazing.

If aboriginal burning did occur, it must have been very labor intensive due to the low fuel levels and generally high moisture levels in the meadows. Reynolds (1959:57) gave evidence from several authors that the meadows, in aboriginal times, were wetter and remained so longer into the summer than they do today. If that was the case, burning would have been even more difficult than it is today. It seems unlikely that the Miwoks would have been interested in undertaking a major effort to burn the high meadows in the dry fall when hunting is generally good anyway (Reynolds 1959:120, 123) and when their staple food, acorns, particularly those of the California black oak (*Quercus Kelloggii* Newb.), ripen in the lower elevations (Barrett and Gifford 1933:142; Thompson 1972:36).

Dudley (1896:264-265) and Loughman (1967:25, 38) described the habit of Sierra sheepmen of setting fire to forests after their flock's departure in the fall, in an effort to increase the

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forage and ease the passage for their sheep. In the lower, drier, and warmer elevations the sheep herders' practice destroyed timber and watersheds (Bade 1905). Because of inadequate fuel and high moisture levels, it is unlikely that the sheep herders succeeded in burning much of the lodgepole forest or the upper elevation meadows.

HUNTING

Miwoks hunted deer (*Odocoileus hemionus* Rafinesque) in the meadows (Bennyhoff 1956:16-17, 19). The deer, being primarily browsers, probably did not have a significant effect upon the herbaceous vegetation (Grinnell and Storer 1924:234; Sumner and Dixon 1953:450-452). The Miwoks may have harvested meadow-inhabiting rodents, but due to the animals' high fecundity, the effects of a harvest were probably slight (Ingles 1965). The local disappearance of the bighorn (*Ovis canadensis* Shaw) can be attributed to sheep herders, recreational hunters, and possibly market hunters, but it is doubtful that the numbers of these animals were ever large enough to have more than a slight influence upon the meadows (Jones 1950; Grinnell and Storer 1924:243; Ingles 1965:443).

SHEEP GRAZING

Sheep grazing is historically the most pervasive of the human-related activities in the meadows.

The value of the Sierra Nevada for sheep pasturage was recognized by the agricultural community as early as 1863 (Perkins 1863:9). Prior to that time, sheep grazing had been confined to other parts of California (Menzel 1944:7-8). The initial catalyst for the movement into the mountains by the sheepmen was probably the drought of 1864-65 (Acting Superintendent 1892:661 and 1894:3; Cain 1961:28; King 1886:46; Loughman 1967:57). Moving up from the lowlands where grass production during droughts was poor, the sheepmen found the mountain meadows to be abundant and good providers (Bridgeport Chronicle Union 1887:May 28). It came to be believed that a summer on the mountain pastures added 1½ pounds of wool to a sheep's fleece (Wentworth 1948:193). A tradition of transhumance developed; sheep were taken into the high meadows just following the retreat of the snowline and were removed prior to the fall storms which began anytime from mid-September to mid-October (Acting Superintendent 1891:4; Benson 1924:2; Martin 1904:1; McClure 1894:169-171; San Francisco Chronicle 1908:October 17).

The numbers of sheep in the Sierra grew rapidly from the 1860's in parallel with a boom in the California sheep industry. In 1859, the state's sheep industry produced 2.3 million pounds of wool; by 1871, production reached 22.1 million pounds (Anonymous 1872). The increase continued until the 1880's when statewide production began to decline rapidly, partially due to competition from South American and Australian wool. This overall decline was not apparent in the Sierra Nevada region, however, where the industry gradually became more concentrated. After the low point of the sheep industry in California in 1900, the production of lambs for meat became important and the industry revived (Martin 1905; Menzel 1944).

The sheep herders divided the mountains among themselves and zealously guarded their own ranges (Benson 1924:1-2). The sheepmen were known to be ambitious in building trails and bridges, and it is quite likely that for many years they were visiting virtually every meadow in the high country with their flocks (Davis undated; McClure 1894). Muir described an example of their ambition:

> Shadow Lake...is everywhere so securely cliffbound that without artificial trails, only the wild animals can get down to its rocky shores from any direction....Year after year I walked its shores without discovering any other trace of humanity than the remains of an Indian campfire....On my last visit... I was startled by a human track, which I at once saw belonged to some shepherd...Returning from the glaciers shortly afterward, my worst fears were realized. A trail had been cut down the mountain-side from the north and all the gardens and meadows were destroyed as if swept by fire. The money changers were in the temple (Muir 1879:416).

The United States Army was put in charge of Yosemite National Park when it was first established in 1890. However, there was a five year delay before effective action was taken against the sheep grazing. Troop "K" of the 4th Cavalry, under the command of Captain Rodgers, cracked down on the grazing in 1895 and 1896, removing tens of thousands of sheep and largely freeing the park of sheep trespassing by 1897 (Benson 1924:1-2; Farquhar 1922:30). The Spanish-American War interrupted efficient operation of the park in 1898 and for the ensuing period of six years, until 1904, the park was left in untrained hands. In some of those intervening years no sheep were removed, while in others up to 190,000 (including repeats) were forced out. In 1904, the Acting Superintendent noted, on the basis of field checking, that there was a probable population of 100,000 sheep in the park. At first, enforcement against grazing was compounded because the park boundaries did not coincide with the easily recognized ones of watersheds. In 1905, the boundaries of the park were aligned with the Sierra crest and, for the first time, the upper reaches of many canyons in the northern portion of the park became closed to sheep (Acting Superintendent 1905:6).

The return of Troop "K" of the 4th Cavalry, in 1905, restored effective protection, and since then sheep trespassing has been virtually nonexistent (Acting Superintendent 1905:6 and 1906:8; Benson 1924:2; Martin 1905).

In summary, Yosemite sheep grazing began in the mid-1860's. The Army's concerted effort to eliminate sheep did not begin until five years after the creation of the park. From 1895 through 1897 sheep were almost eliminated, only to return with the departure of competent personnel in 1897. Sheep were abundant, particularly in the northern part of the park, until their final removal in 1904 and 1905. The numbers of sheep were in the thousands and probably over one hundred thousand for many summers. They affected an area consisting of many tens of thousands of acres of prime recreational land (Bradley 1911; Sumner 1947).

Despite their lengthy presence and large numbers, there exists substantial evidence that the sheep's impact was minimal. Talbot and Sampson (1948:557) pointed out two assets which these meadows had for grazing: green grass and abundant water supply during the late season. Access to the upper meadows was delayed by snow on the passes and, as a result, plants could generally achieve some growth in the spring prior to grazing. Burcham (1957:204) explained the importance of this delay, "grazing too early in the spring is particularly detrimental to perennial plants, where leafage, needed for the manufacture of food, is removed before the plants have had time to replenish root reserves or to produce seeds."

According to a Department of Agriculture report (1933:26), the common practice in high mountain regions has been for the sheep herder to "direct, rather than herd, his sheep in an effort to utilize the feed more fully." This lessens the likelihood of destroying the grazing resource by concentrated grazing and trampling. The mountain meadows have a high grazing capacity per unit of meadow area (Stoddart and Smith 1943:110). Overall, the higher mountain areas are classified in the "open forest" range type by the U. S. Forest Service, with a grazing capacity of about one sheep per acre per month (U. S. Forest Service 1936:101, 107). Estimating that the lodgepole-subalpine and alpine ecosystems make up 406,500 acres in Yosemite, the area should be capable of withstanding about 400,000 sheep in the grazing season. The estimate of one or two hundred thousand sheep during its peak use thus represents a fraction of the range's capacity.

Other evidence of the time-limited impact of sheep grazing comes from many sources. The higher regions of the Sierra Nevada were placed by the U. S. Forest Service (1936:109) in the lowest classification for range depletion (0-25%), a category into which only the 13% of the western range fit.

In 1900, Lincoln Hutchinson wrote of the northern Yosemite region:

> Going as we did into the most remote corners of the park, and in a year when the troops were mostly engaged elsewhere, we could not but have some misgivings as to the possibility, or even the probability, of finding evidence of the havoc wrought by the sheepmen. It was an agreeable surprise, therefore, to find only the very slightest traces of the presence of the sheep. The meadows are green and luxuriant, the exquisite mountain flowers are blooming in profusion, and whole forests of tiny new conifers are springing up in spots which for years have been bare (Hutchinson 1900:163).

Muir (1896:273) visited the park in 1895, just one summer after the efficient work of the army had begun, and he reported:

> In the highlands of the park the tough sod of the glacier meadows was never wholly destroyed, but their delicate grasses were not allowed to bloom beneath the feet of the trampling sheep, and all the bright flowers that so charmingly enameled the close, smooth sod-gentians, daisies, ivesias, orthocarpus, bryanthus, etc. - vanished as if not a root or seed had been spared. This year, I am happy to say, I found these blessed flowers blooming again in their places in all the fineness of the wilderness. . . nearly every trace of the sad sheep years of repression and destruction having vanished.

Good evidence concerning the continuity of the sod cover at the end of the 19th century is to be found in an examination of the Sierra Club Photograph Collection in the Bancroft Library at the University of California at Berkeley. This collection of approximately 5,000 photographs includes hundreds from Yosemite Park taken near the turn of the century. Many are of excellent quality and those of Joseph N. LeConte, in particular, show the meadow plants in great detail. In these photographs, the groundcover is very similar to that existing today.

Colonel Benson (1924:1-2) stated that sheepmen divided up the range and controlled individual portions for their herds. Possession of individual grazing "rights" and maintenance of continual grazing for 29 years before the park was formed, tends to indicate that the sheep herders had some concept of grazing capacity.

PACKSTOCK GRAZING

Grazing by packstock has existed since the earliest visits by non-Indians. Its effects are sometimes difficult to assess because, as Sharsmith (1959:116) stated, above 2750 m (9000 ft) in Sequoia and Kings Canyon National Parks, and above a somewhat lower altitude in Yosemite, nonnative plants, which are typical indicators of disturbed conditions, are rare or absent because they are climatically unsuited to the higher altitude. He further stated that, "At higher altitudes . . . the only indicators available are the usual appearances of an overgrazed areas as shown by the thinning of ground cover, bare spots, incipient gullying, and evidence of increased erosion . . . . The mere presence or even abundance of various non-palatable native species . . . may or may not be indicators of overgrazing, notwithstanding the fact that they often increase in abundance when overgrazing occurs" (Sharsmith 1959:116-117. Disturbance of meadows can occur rapidly and in certain sites extremely heavy grazing can eliminate possibilities for recovery in the foreseeable future (Giffen et al. 1970:17; Sharsmith 1961). Sharsmith (1961:49) and Bennett (1965:62) pointed out that allowing pack animals to graze freely without being tethered or corraled substantially reduces the detrimental effects of grazing. Concentrated grazing occurred near the High Sierra Camps and in a few other areas (Ernst 1949; Sharsmith 1961). Sharsmith, in his 1961 review of the Yosemite grazing situation, suggested that packstock grazing has had little effect on most of the backcountry. At the present time, packstock use is low, except on the trails between the High Sierra Camps.

Wood (1975a:7-9) showed a relationship between drainage-basin area and valley gradient, which differentiates stable from unstable meadows vulnerable to gully erosion. He emphasized that grazing should be carefully controlled in gully-prone meadows (Wood 1975b).

HIKING AND RIDING

Hiking and the riding of horses (often accompanied by packstock) have established trails and defoliated areas throughout the backcountry. Trails have developed both parkwide and in the vicinity of most campsites. Zonation of vegetation adjacent to trails was noted by Bates (1935:470) and by Dale and Weaver (1974:767-772). This may be caused by the trail having influenced the light, soil moisture, and the temperature in the adjacent areas and/or by the fact that people frequently walk beside established trails, thereby trampling and destroying plants.

Trail width was found by Dale and Weaver (1974:768, 771) to be generally greater in forests than in meadows; at a high level of use, this trend reversed. Bayfield (1971) devised a technique for comparing the tendencies of hikers to spread out laterally across the trail corridor. Bayfield (1973:635-644) found that increased wetness and roughness of the path surface, or increased slope of the path tended to result in wider trails. However, the rougher the ground adjacent to the trails, the less the people tended to move off them. Hikers were observed by Bayfield to take the most convenient route in terms of surface or direction, thus affecting the subsequent development of the path. He observed evidence of a

continuing increase in widths of paths on curves, but a relatively stable lateral distribution of users on straight sections. He also stated that there was a greater tendency for walkers to leave the path when coming downhill.

After having had the opportunity to observe hikers over hundreds of miles of trails in the Sierra Nevada, it is possible to list the factors which motivate hikers to leave the trail treadway in three categories: (1) avoidance of undesirable features, (2) attraction to especially desirable features, and (3) fulfillment of a psychological need. These different factors can individually or collectively influence a person's behavior. Itemization of the different features or needs under each category clearly shows the complications inherent in trail design and hints at the extent of trail widening problems in Yosemite, Table 1.

TABLE 1. Reasons for which hikers deviate from the trail surface of treadway.

1. Avoidance of:
   a. Traction loss: sand, gravel, steep slope, and snow banks;
   b. Roughness: pebbles or rocks, and snow banks;
   c. Wetness: muddiness, standing water, and snow;
   d. Obstacles: fallen trees, large rocks, and water gates;
   e. High steps: large rocks on slopes;
   f. Elevation change;
   g. Entrenched trail where ankles hit;
   h. Another hiker or pack animals.

2. Attraction to:
   a. Better traction;
   b. Smoother surface;
   c. Drier surface;
   d. Shorter route;
   e. Coolness: shade;
   f. Warmth: sunlight;
   g. Very rapid elevation changes;
   h. Destination for view, drink and rest;
   i. Side-by-side companionships with other hikers.

3. Fulfillment of:
   a. The need to be an individual: the 'pathfinder phenomenon';
   b. The need to easily conduct a conversation.

Bates (1938:453) pointed out that compared with humans, "a much greater weight is carried per unit area by the feet of animals." As a result, they can compact soil much more than hikers. Observations of the devastating effects of the passage of a few dozen pack animals across a narrow corridor in a moist meadow is convincing evidence of their capability to strip an area of vegetation cover many times faster than hikers. Pack animals sink to a far greater depth in wet meadows than do people. Furthermore, a meadow has to be very wet before a pack animal will balk at crossing, whereas a person will generally avoid such an area whenever possible. Finally, the pack (or riding) animal frequently will drag its feet, especially if being led in a closely tied pack string, thus loosening the soil. The advantage that the pack animal has over the person, in terms of mitigating its impact, is that it tends to stay on a trail more readily. This latter observation concurs with the findings of Dale and Weaver (1974:768) in the Rocky Mountains, where trails used by both horses and hikers are deeper and similar in width, or slightly narrower, than those only used by comparable numbers of hikers.

Beyond the areas immediately adjacent to trails, where use by people and horses was limited, we could find very little evidence of the trails affecting the vegetation. The borders of plant communities in Rafferty Meadow for example, when viewed from the air, showed no indication of having been disturbed by the deep trail that bisects the meadow. Viewed from the ground, vegetational composition seemed undisturbed, except within a few centimeters of the trail. On abandoned treadways one may frequently find plants that are not members of the immediate surrounding community. Extensive examination of meadow trails throughout Yosemite has convinced me that they very rarely influence the likelihood of the meadows being invaded by lodgepole pines, with the exception of along the narrow strips where the trails reside. Lodgepole pine invasions do not consistently occur in meadows with trails and frequently are found in meadows without trails.

Although the soils of the higher elevations probably do not contain substantial numbers of small subterranean fauna, what fauna there are may be limited in their movements by the compaction and other alterations that may occur beneath trails. To my knowledge no research on this topic has been done in the High Sierra, but there have been studies of this nature in Britain, where a general reduction in soil fauna beneath trampled areas was noted (Chappell et al. 1971; Duffey 1975).

Compaction may discourage rodents from digging through the hardened soil. They may also be discouraged from digging beneath a trail whose depth is close to or reaches the watertable.

The problem of widening and multiplying trails is generally restricted to the established trail network in Yosemite, although a few new trails are developing. This network of course includes established camp areas.

CONCLUSION

It can be reasonably stated that, with the exception of specific locations that have been heavily grazed by packstock or trampled by people and packstock, the cultural activities of burning, hunting, grazing, hiking, and horseback riding seem to have had no lasting effects on the vegetation of the high meadows of Yosemite National Park.

LITERATURE CITED

ACTING SUPERINTENDENT. 1891, 1892, 1894, 1904, 1905, 1906. Report of the Acting Superintendent of Yosemite National Park. Assorted lengths.

ANONYMOUS. 1872. Sheep Farming in California, Overland Monthly 8(6).

BADE, WILLIAM FREDERIC. 1905. Forests in Tuolumne, Sunset 14:597-603. April.

BARRETT, S. A. and E. W. GIFFORD. 1933. Miwok Material Culture; Indian Life of the Yosemite Region, Bulletin, Public Museum, Milwaukee 2(4):119-377. March. Reprinted without date by Yosemite Natural History Association, Yosemite, Ca.

BATES, G. H. 1935. The Vegetation of Footpaths, Sidewalks, Carttracks and Gateways, Journal of Ecology 23:470-487.

_____. 1938. Life Forms of Pasture Plants in Relation to Treading, Journal of Ecology 26: 452-454.

BAYFIELD, NEIL G. 1971. A Simple Method for Detecting Variations in Walker Pressure Later-

ally Across Paths, Journal of Applied Ecology 8:533-535.
___ ___. 1973. Use and Deterioration of Some Scottish Hill Paths, Journal of Applied Ecology 10(2):635-644.
BENNETT, PETER S. 1965. An Investigation of the Impact of Grazing on Ten Meadows in Sequoia and Kings Canyon National Parks. M.A. Thesis, Department of Biology, San Jose State University, California. Unpublished. 164 pp.
BENNYHOFF, JAMES A. 1956. An Appraisal of the Archaeological Resources of Yosemite National Park. Reports of the University of California, Berkeley. 71 pp. plus 23 tables and 11 figures.
BENSON, HAROLD C. 1924. Letter to Mr. Chester Verteeg, Los Angeles. In Benson file, Yosemite National Park Research Library. July 18. 6 pp.
BILLINGS, W. D. and H. A. MOONEY. 1968. The Ecology of Arctic and Alpine Plants, Biological Review 43:481-529.
BOCHE, KENNTH ERNEST. 1974. Factors Affecting Meadow-Forest Borders in Yosemite National Park, California. M.A. Thesis, Geography Department, University of California at Los Angeles. Unpublished. 116 pp. plus maps.
BRADLEY, HAROLD C. 1911. The Passing of Our Mountain Meadows, Sierra Club Bulletin 8:39-42 plus plates.
BRIDGEPORT CHRONICLE-UNION. 1887. Bridgeport, California. Sheep, on p. 3, May 28.
BRIGGS, GEORGE S. 1966. Yosemite National Park, A Report on Backcountry Conditions and Resources, with Management Recommendations. Unpublished Report, Yosemite National Park Research Library. 217 pp.
BURCHAM, L. T. 1957. California Range Land, An Historico-Ecological Study of the Range Resources of California. Division of Forestry, Department of Natural Resources, State of California, Sacramento. 261 pp. plus 2 maps.
CAIN, ELLA M. (CODY). 1961. The story of Early Mono County. Fearon Publishers, Inc., San Francisco. 166 pp.
CHABOT, BRIAN F. and W. D. BILLINGS. 1972. Origins and Ecology of Sierra Alpine Flora and Vegetation, Ecological Monographs 42:163-199.
CHAPPELL, H. G., J. F. AINSWORTH, R. A. D. CAMERON and M. REDFERN. 1971. The Effect of Trampling on a Chalk Grassland Ecosystem, Journal of Applied Ecology 8:869-882.
DALE, D. and T. WEAVER. 1974. Trampling Effects on Vegetation of Trail Corridors of North Rocky Mountain Forests, Journal of Applied Ecology 11(2);767-772.
DAVIS, MILTON F. Undated. A photograph in the Francis P. Farquhar Papers in the Bancroft Library. The caption reads, "Sheep Crossing San Joaquin River at high water. My troop of horses walked the same log (flattened) without accident." Photograph from the U. S. cavalry days in Yosemite.
DEPARTMENT OF AGRICULTURE. 1933. Range Sheep Production. Farmers Bulletin 1710. U. S. Government Printing Office, Washington, D. C. 34 pp.
DEPARTMENT OF INTERIOR. 1975. Management Ecosystems Map, 1:125,000, of Yosemite National Park. Resources Management Division Office.
DOBSON, HEIDI E. M. 1975. Study of the Phenology of Subalpine Plants in Yosemite. Unpublished Report, Research Scientist's Office, Yosemite National Park. 24 pp.
DUDLEY. 1896. Sierra Club Bulletin. Pp. 264-265.
DUFFEY, ERIC. 1975. The Effects of Human Trampling on the Fauna of Gassland Litter, Biological Conservation 7(4):255-274.
ERNST, EMIL F. 1949. The 1948 Saddle and Pack Stock Grazing Situation of Yosemite National Park. Unpublished report. 77 pp. plus 52 unnumbered figures, 1 map.
FARQUHAR, FRANCIS P. 1922. Some Battles in the Sierra, Trails - Devoted to Mountaineering 2(1):27-30. Journal of the California Alpine Club.
GIBBENS, ROBERT P. and HAROLD F. HEADY. 1964. The Influence of Modern Man on the Vegetation of Yosemite Valley. Division of Agricultural Sciences, University of California, California Agricultural Experiment Station Extention Service Manual 36. 44 pp.
GIFFEN, ALEC, C. M. JOHNSON, PAUL ZINKE and ARNOLD SCHULTZ. 1970. Ecological Studies of Meadows in Lower Rock Creek, Sequoia National Park, Progress Report for 1969. School of Forestry and Conservation, University of California at Berkeley. 43 pp.
GRINNELL, JOSEPH and TRACY IRWIN STORER. 1924. Animal life in the Yosemite. University of California Press, Berkeley. 752 pp. including illustrations.
HOLMES, DANIEL O. and HEIDI E. M. DOBSON. 1976. The Effects of Human Trampling and Urine on Subalpine Vegetation, a Survey of Past and Present Backcountry Use, and the Ecological Carrying Capacity of Wilderness, Yosemite National Park, Sierra Nevada, U. S. A. Unpublished report in Office of Research Scientist, Yosemite National Park, Ca. 247 pp. including illustrations and maps.
HUTCHINSON, LINCOLN. 1900. Ascent of Matterhorn Peak, Sierra Club Bulletin 3(2):159-163.
INGLES, LLOYD G. 1965. Mammals of the Pacific States. Stanford University Press, Stanford. 506 pp.
JONES, FRED L. 1950. A Survey of the Sierra Nevada Bighorn, Sierra Club Bulletin 35(6): 29-76. Based upon M.A. Thesis, same author.
KING, CLARENCE. 1886. Mountaineering in the Sierra Nevada.
LECONTE, JOSEPH N. 1907. The High Sierra of California, Alpina Americana 1:1-16 plus 6 plates. American Alpine Club, Philadelphia.
LOUGHMAN, MICHAEL LAWRENCE. 1967. National Parks, Wilderness Areas, and Recreation in the Southern Sierra Nevada, California: A Historical Geography. M.A. Thesis, Geography Department, University of California at Berkeley.
MARTIN, W. J. 1904 and 1905. Letters to the Adjutant in Yosemite National Park reporting on illegal sheep grazing in the park.
MCCLURE, N. F. 1894. Explorations Among the Canons North of the Tuolumne River, Sierra Club Bulletin 1(4):168-189.
MENZEL, MARION LEE. 1944. The Historical Geography of the Sheep Industry of California in the Nineteenth Century. M.A. Thesis, Geography Department, University of California at Berkeley.
MUIR, JOHN. 1879. The Mountain Lakes of California, Scribner's Monthly 17:411-420.
_____. 1896. Address given to the annual meeting of the Sierra Club held November 23, 1895. Published in the Sierra Club Bulletin 1(7): 271-286.
_____. 1961. The Mountains of California. Doubleday and Company, Garden City. 300 pp. Originally published in 1894.
PERKINS, JAMES E. 1863. Sheep Husbandry in California. Speech. Towne and Bacon, San Francisco. 15 pp.
REYNOLDS, RICHARD D. 1959. Effect of Natural Fires and Aboriginal Burning Upon the Forests of the Central Sierra Nevada. M.A. Thesis, Geography Department, University of California at Berkeley. Unpublished. 262 pp.
RUSSELL, CARL PARCHER. 1927. What Becomes of Our Mountain Meadows? Yosemite Nature Notes 6(5):37.
SAN FRANCISCO CHRONICLE. 1908, October 17. Storm Sweeps High Sierra. San Francisco, California.
SHARSMITH, CARL W. 1959. Report on the Status, Changes and Ecology of the Back Country Meadows in Sequoia and Kings Canyon National Parks. National Park Service. Unpublished report.

120 pp.

_____. 1961. A Report on the Status, Changes, and Comparative Ecology of Selected Backcountry Areas in Yosemite National Park that Receive Heavy Visitor Use. Unpublished. Unnumbered.

STODDART, LAURENCE A. and ARTHUR D. SMITH. 1943. Range Management. McGraw-Hill Book Company, Inc., New York. 547 pp.

SUMNER, LOWELL. 1947. Protecting Mountain Meadows, Sierra Club Bulletin 32(5):53-62 plus plates.

SUMNER, LOWELL and JOSEPH S. DIXON. 1953. Birds and Mammals of the Sierra Nevada with Records from Sequoia and Kings Canyon National Parks. University of California Press, Berkeley. 484 pp.

TALBOT, M. W. and A. W. SAMPSON. 1948. The Range in California, *in* Grass: Yearbook of Agriculture 1948. U. S. Department of Agriculture. U. S. Government Printing Office, Washington, D. C. Pp. 575-582.

THOMPSON, STEVEN and MARY. 1972. Wild Food Plants of the Sierra. Dragtooth Press, Corvallis. 186 pp.

TRANQUILLINI, W. 1964. The Physiology of Plants at High Altitudes, Annual Review of Plant Physiology 15:345-362.

U. S. FOREST SERVICE. 1936. The Western Range. U. S. Government Printing Office, Washington, D. C. 620 pp.

WENTWORTH, EDWARD MORRIS. 1948. America's Sheep Trails.

WOOD, SPENCER HOFFMAN. 1975a. Holocene Stratigraphy and Chronology of Mountain Meadows, Sierra Nevada, Ca. Ph.D. Dissertation, California Institute of Technology, Pasadena. Unpublished.

_____. 1975b. Abstract to lecture given to the Annual Joint Meeting on Research in Sequoia, Kings Canyon, and Yosemite National Parks. August.

MANAGEMENT STUDIES OF HUMAN IMPACT AT BACKCOUNTRY CAMPSITES IN OLYMPIC NATIONAL PARK, WASHINGTON

Bruce B. Moorhead[1] and Edward S. Schreiner[2]

INTRODUCTION

The impact of human trampling upon vegetation and soils has been investigated since the early 1900's. Recent literature reviews of the subject by Dale (1973), Speight (1973) and Liddle (1975) indicate that human trampling can increase exposure of mineral soil, erosion, soil compaction, the loss of plant cover and biomass, and cause changes in species composition including the introduction of "weedy" species.

Studies of the effects of recreational trampling on vegetation have been underway in Olympic National Park since 1970. Bell and Bliss (1973) examined the results of controlled trampling on two alpine plant communities, and Schreiner (1974) treated three subalpine communities in a similar manner. Both investigations measured plant cover reduction as the level of human trampling was increased, and both found the drier sites to be more sensitive. However, both were conducted in the northeastern corner of the park, representing a small portion of the diverse environmental gradients and plant communities. Both studies, moreover, were short-term experiments and could not evaluate soil and plant community changes due to long-term trampling.

This paper reports on the results thus far of an investigation beginning in 1973 to obtain information for park managers about the extent, severity and control of human recreational impact throughout the backcountry of the park. In the past 10 years more than a threefold increase has occurred in activities such as hiking and overnight camping (Figure 1). At numerous backcountry campsites, concentrated trampling has eliminated low vegetation in visible "pads" of bared soil, ranging from 1 to 30 meters in diameter. Detailed information about such trends, and how to redirect and minimize them, has become essential to an adequate protective management of this "wilderness" park.

Specific objectives in this investigation have been: 1) to establish a baseline inventory of human impact throughout the park so changes and trends can be monitored with time; 2) to devise methods giving an accurate quantitative description of conditions resulting from human trampling; and 3) to obtain information and expertise enabling improved on-site management of backcountry camp areas.

STUDY AREA

Olympic National Park is located on the Olympic Peninsula of Washington State in the Pacific Northwest of the United States. Created in 1938, the park consists of over 363,000 hectares in two units: the interior, mountainous portion of the Olympic Peninsula, and an 80 kilometers long coastal strip, fronting the Pacific Ocean. The climate is wet-maritime with a pronounced precipitational cline resulting from the orographic effect of the Olympic Mountains, 40 km inland and over 2,400 meters in elevation, intercepting moist westerly winds off the Pacific Ocean. In annual rainfall this gradient ranges from 200 to 500 centimeters along the western slopes and valleys to a "rain shadow" of about 50 cm on the northeast side of the mountains. Mean annual temperatures range from 1 to 17° Celsius. With such abundant moisture and a cool climate, massive, mixed-coniferous forests predominate in a dozen or more communities between sea level and glaciated peaks. In the upper elevations, subalpine communities of interspersed forest-meadow extensively occur, often associated with tarn lakes.

METHODS

Throughout this paper, the terms "camping areas," "camping locations," and "campsite" are used. Camping areas, or locations, are groups of campsites occurring together. They can occur along trail corridors or at places with some particular attraction, such as a high lake. Campsite, or site, indicates the specific place where people pitch a tent. Most such places have a fire-ring, unless fires are prohibited. In any case, a trampled area is evident.

Severe work constraints imposed by foot travel, remote trail distances, rugged terrain, unpredictable weather, and limited summer access were met by using standard plant community measures in modified form, or by devising our own measures where necessary. As a first procedure at camping locations, we mapped the component campsites by a hand compass and pacing survey (Figure 2). Aerial photos were used where available and helpful. These baseline maps are a primary and most practical means of relocating and remeasuring campsites at a remote location. Thus far, in our experience, all sites have been relocatable by this method.

Over 40 biophysical and management data were characterized or measured at each site. An edge-punch, keysort card was designed with the assistance of McBee Keysort Systems of Bellevue, Washington, to assist in organizing the field data acquisition. The original idea for using such cards to survey dispersed recreation sites was developed by Hendee et al. (1976) at the Wildlands Recreation Unit of the U. S. Forest Service in Seattle, Washington. Our design goes further in allowing actual quantification of impact characteristics among varied and similar areas.

Tree canopy estimates were made by the observer standing at the center of the campsite and, while looking directly overhead, estimating overstory cover classes by percent increments, e.g., 0, 1-20, 21-40, etc. Understory vegetation was recorded as the species rank of visual importance in the immediate perimeter of the site. Other ecological measures included percent slope, aspect, elevation, percent coarse gravel fraction at the surface, and lowest continuous height of lichen (*Alectoria* spp.) on trees surrounding the campsite. Lichen height was used as an indirect measure of winter snow depth.

The most visible and measurable evidence of

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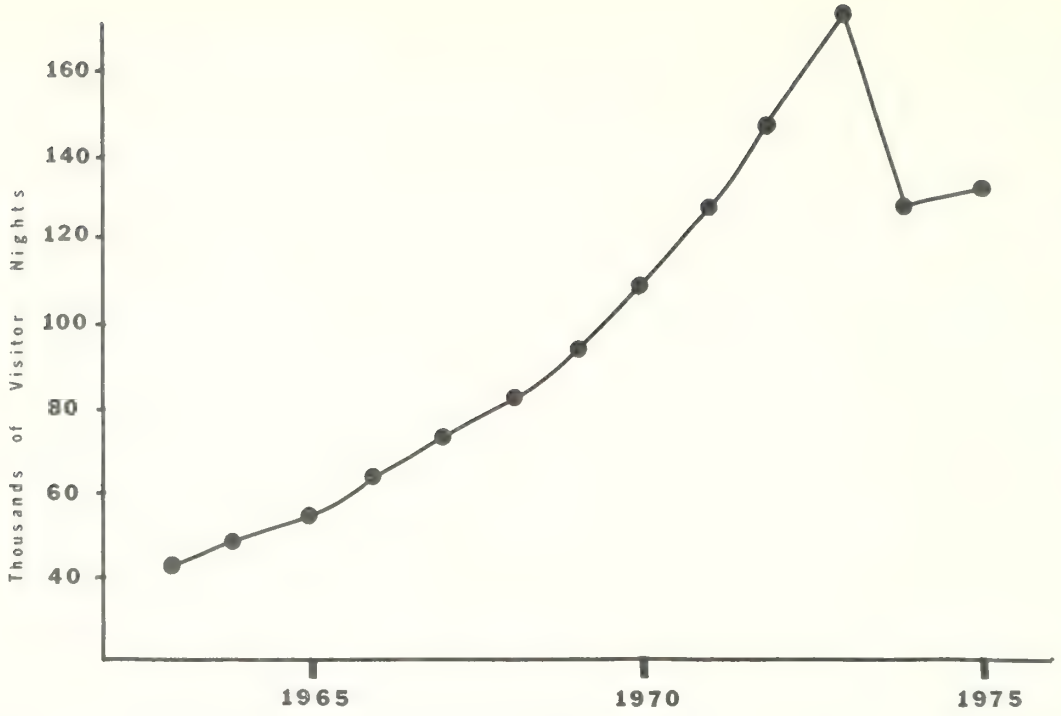

FIGURE 1. Backcountry overnight use in Olympic National Park between 1963 and 1975.

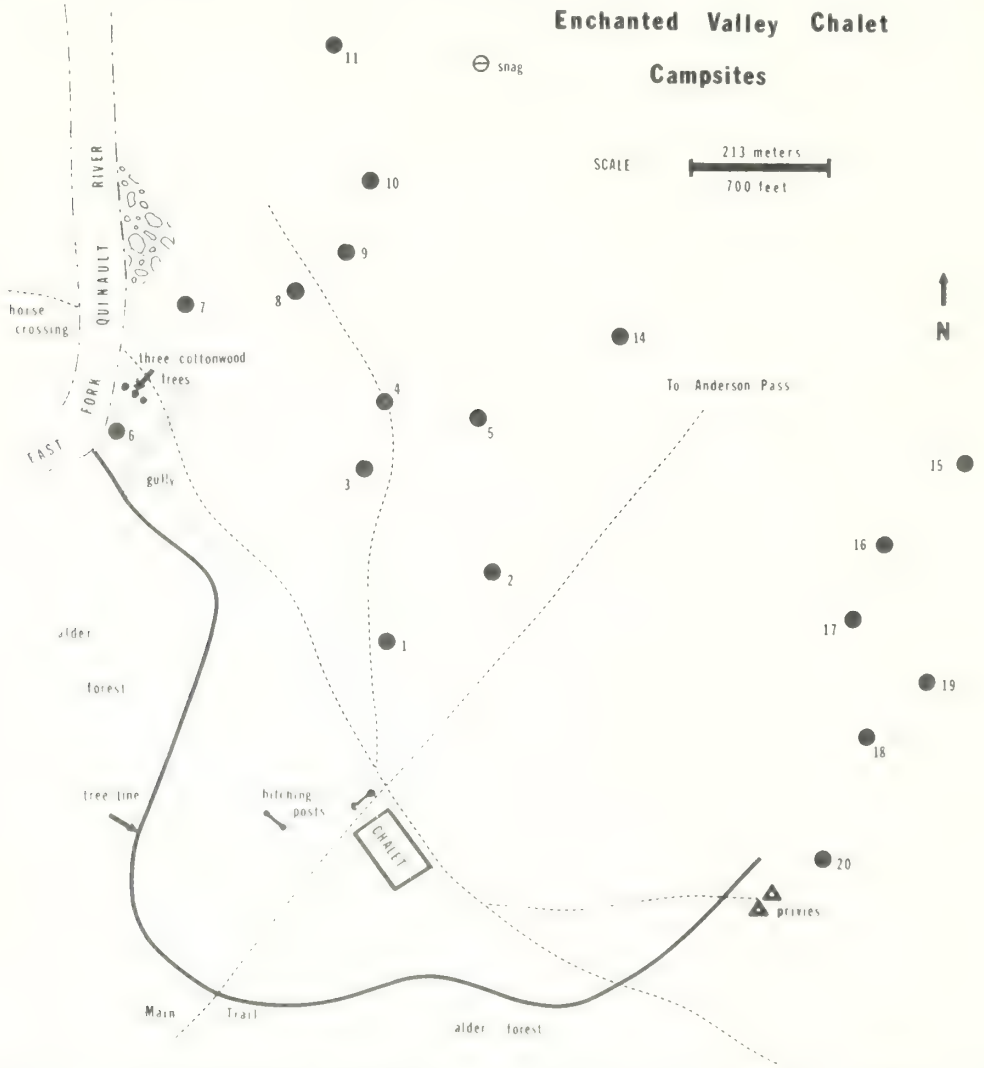

FIGURE 2. Baseline map of campsites at Enchanted Valley chalet, Quinault River trail, Olympic National Park.

human activity at a site was the amount of bared soil from a reduction of vegetation cover by concentrated trampling. A modified line-intercept plot technique was devised to measure the size characteristics of "bare ground" at campsites. Eight line intercepts, radiating in 8 cardinal directions from the center of a site, were successively read along each until the first green, herbaceous plant was encountered. The shape and radial size of bare ground at the campsite was thereby described as a variable, eight-sided polygon. The amount of bared soil for comparative purposes was expressed as the average radial length of all 8 intercepts at a site, or as the total area of a circle with this average radius. The total area trampled bare at a camping location was expressed as the average radius of all component sites, or as the composite square-meters-area from summing respective circle-areas of each site at that location. Evident paths and other unplanned trails crossing the immediate perimeter of a campsite were defined as "social trails." For comparative purposes among camp locations, they were expressed as the average number per campsite, or the total per camping location.

Data tabulations and calculations were completed by the CDC 6400 computer at the University of Washington through the Cooperative Park Studies Unit, College of Forest Resources. Our analyses thus far have employed non-parametric statistics and Kendall rank correlation coefficients to examine association patterns among site variables.

RESULTS

Thus far, 73 backcountry camping areas, including 726 individual campsites, have been investigated (Figure 3). Computer summaries of selected data were generated in tabular form for the immediate benefit of respective area managers.

Table 1 is a sample area summary in 1975 for 27 campsites at Enchanted Valley chalet along the upper Quinault River trail. Managers are informed in this summary, among other things, of the current condition and effectiveness of the privy (outdoor toilet), i.e., how full of excrement and how distant it is from most of the sites at this location. The average proximity of sites to water is also calculated, both as an index of water availability and potential sanitation problems. Relative trampling impact is indicated by the number and density of campsites, as well as the average "bare ground" radius per site and the number of sites with a radius of over 3 meters (10 ft.) of bared soil. The "number of sites with fire-rings obliterated" is a tally of recent efforts by field personnel at that location to eliminate rock cairns that identify new campsites. This figure also provides a benchmark of apparent new sites at the location. Each summary is complemented by a baseline map of the camping area (Figure 2).

While mapping the camping locations, it became apparent that zones of concentrated trampling associated with repetitive campfire building are the most extensive, measurable evidence of human impact throughout the backcountry. The emergence of individual or aggregated campsites, moreover, indicates a successional process as reflected in the history, changing distribution and density of sites, and their measurable plant cover changes at a particular location.

A pattern of campsite succession is often catalyzed by some local attraction, e.g., a nearby fishing spot, and a nucleus of one or two campsites initially appear. Then, depending on spatial camping options, proximity to the trailhead, strength of the attraction, etc., other sites appear in time as "satellites" to the originals. The number of sites may increase to from 12 to 35 campsites at a location which can enlarge the affected area from about 30 to 1,700+ meters (100 to 5,600+ ft.) in diameter.

In this process, the original sites, which are often close by a major trail where level tent spots and water occur, serve as "primary" campsites--those used most often at that location. They are distinguished by their bared soil "pads" with trampled radii of typically 3+ m (10+ ft.), or 28+ square-meters (314+ $ft.^2$), and often from 6 to 12 social trails radiating from each. Moreover, at 7 of the locations thus far investigated, trampling progression at the primary sites has interconnected in a continuous "sprawl" area of over 120 square-meters (1,300+ ft^2) of bared soil. These occur notably at certain high lakes and trail shelters.

Attempts to examine the relationships of these bared areas to other site variables have not been completed throughout the park, but initial results suggest certain association patterns. Table 2 is a list of Kendall correlation coefficients comparing the radial size of bared ground with 13 other variables at 51 campsites along 26 km (16 miles) of Elwha River trail. Nine variables show correlations ($P = \leq .05$) with the size of bared area. They suggest that, along this major trail at least, the trampled area at campsites increases as percent tree overstory, number of overstory layers, percent surface gravel, gravel particle size, number of social trails, and site density increase. Conversely, that bared area at campsites decreases as distance from the privy, distance from the trailhead, and percent slope increase.

It is also evident that trampling impact is generally heaviest, i.e., total bared area per camping location, within about the first 12 km (7.5 miles) of a trail. Table 3 ranks 17 popular camp areas by their distance from respective trailheads and compares their total bared soil area and 1975 visitation. Although visitor uses are evidently quite high at some locations 20+ km up the trail, bared soil area per location decreases beyond 12 km.

Tables 4 and 5 are correlation coefficients relating bared soil area to the number of social trails, percent forest overstory, and percent surface gravel at campsites within, respectively, 9 lowland and 8 subalpine camping locations. They reveal that rather strong association patterns ($P = \leq .20$) can occur *within* camping areas at various elevations. The number of social trails around a campsite do often increase significantly ($P = \leq .10$) as bare ground from trampling increases. The tables also suggest that with increasing forest canopy over a site and where a high percent of surface gravel occurs at subalpine locations trampling impact may often be expected to occur more significantly at individual campsites. Attempts to relate these and other site variables *between* camp areas have indicated no correlation or inconsistent results suggesting thus far that no broad patterns between visitor impact and biological factors hold throughout the park.

CONCLUSIONS

This investigation has directly aided in the preparation of a Backcountry Management Plan for Olympic National Park by furnishing detailed baseline information about campsites and specific measures to improve site management. The following recommendations are offered:

TABLE 1. Computer summary of backcountry campsite characteristics in 1975 at Enchanted Valley chalet, Quinault River trail, Olympic National Park.

ENCHANTED VALLEY CHALET ,EAST FORK QUINAULT RIVER NUMBER OF SITES 27

ELEVATION....2000 FEET

VEGETATION ZONE.... MONTANE

DISTANCE TO NEAREST TRAILHEAD....11.9 MILES

PRIVY.... YES

CONDITION.... 0-1/4 NUMBER SITES OVER 400 FT FROM PRIVY....12

ATTRACTIONS AND OPPORTUNITIES.. DESTNATN FISHING SCENIC

AVERAGE NUMBER OF SOCIAL TRAILS PER SITE.... 2.15

AVERAGE DISTANCE TO WATER.... 226.11 FT

NUMBER OF SITES WITH VISIBLE EROSION.... 2

NUMBER OF SITES WITH FIRE RINGS OBLITERATED.... 0

AVERAGE PERCENT CROWN COVER.... 23.70

AVERAGE BARE GROUND RADIUS PER SITE.... .52 METERS

NUMBER OF SITES OVER 3 METERS AVE BARE GRND RADIUS.... 1

AVE NUMBER SITES WITHIN 200 FT OF EACH OTHER... 3.63

AVE DISTANCE TO NEAREST SITE FOR EACH SITE.... 115.15 FT

DATE INFORMATION RECORDED.... 8 5 75

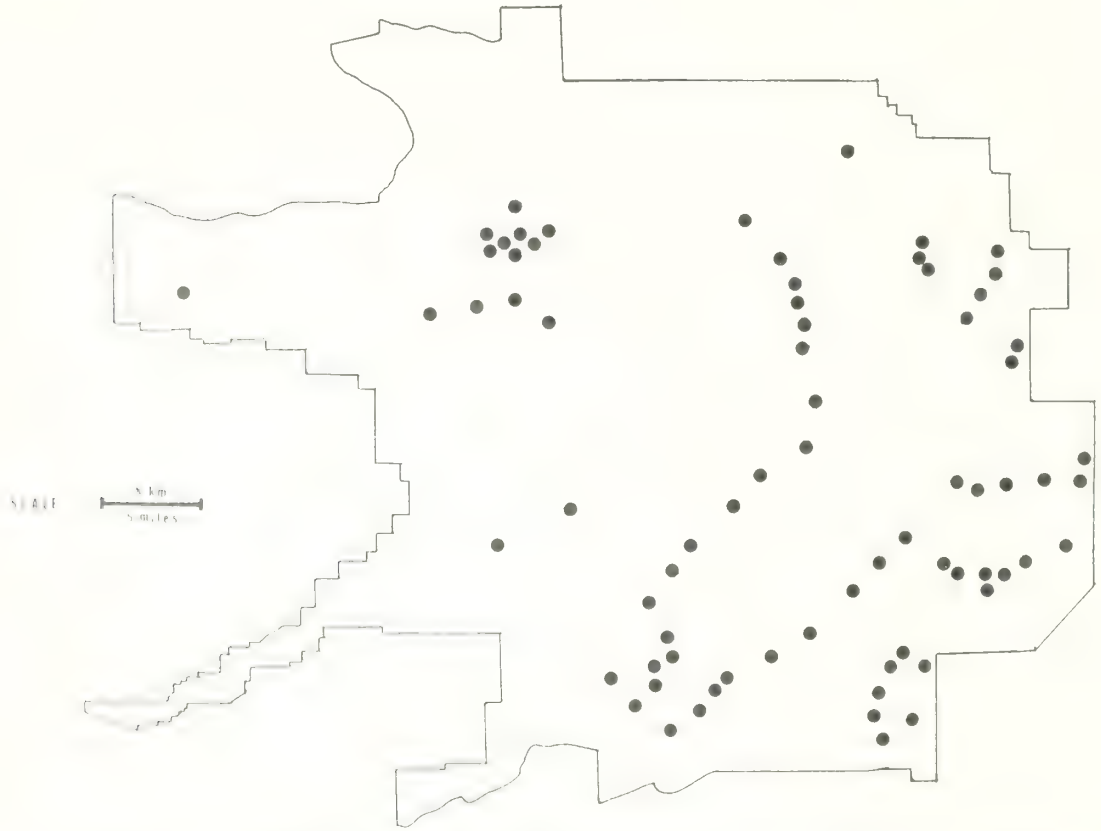

FIGURE 3. Backcountry camping areas investigated in the interior portion of Olympic National Park. Pacific Ocean coastal portion not shown.

1. As a general practice, limit campfire building activities to lowland and montane forest communities with greater biomass and plant productivity, in the sense of increased recovery potential from trampling.

2. Redirect the trend of proliferating campfire sites and "satellites" around primary campsites by obliterating new sites as they appear. These new sites evidently create new, quasi-destinations for hikers and enlarge the social zone of trampling at established camping locations.

3. Reduce trail-braiding and the number of social trails at camping locations by small directional aids to clarify essential routes and reduce searching behavior.

The results of our data analyses thus far indicate few broad patterns between human impact and biological factors that hold throughout the park. We attribute this to the heterogeneity of terrain and plant community factors, which results in a significant variability between individual camping areas. When applied to improving any overall management strategy, this suggests that realistic attempts to model carrying capacity will require a precise determination of ecological

TABLE 2. Kendall rank correlation coefficients (r) associating the radial size of trampled-bare sites with 13 other variables at 51 campsites along 26 km of the Elwha River trail in Olympic National Park. s = significance level.

Variable	r	s
Number of tree overstory layers	.51	.01
Percent gravel (coarse fraction)	.37	.01
Percent tree overstory	.35	.01
Distance to the privy	-.28	.01
Distance to main trail	-.27	.01
Number of social trails	.27	.01
Number of sites within 60 m	.24	.03
Percent slope	-.22	.05
Gravel particle size	.21	.05
Distance to water	-.15	
Tree height	.13	
Number of horse pads	.10	
Distance to nearest campsite	-.05	

TABLE 3. Visitor use and trampling impact (total bared-soil area) at 17 backcountry camp locations ranked by their distance from the trailhead. N = 256 campsites.

Camp location	Trailhead distance (km)	Bared-soil area (m^2)	Visitor nights 1975
Lake Constance	3.2	1,159	643
Camp Pleasant	3.9	1,240	2,357
Sand Point	4.8	3,792	7,933
Grand Lake	5.6	1,092	1,760
Flapjack Lakes	5.6	1,120	1,929
Deer Lake	6.6	905	1,468
Lillian Shelter	7.2	1,535	767
Happy Four	8.7	72	1,943
Royal Basin	12.1	944	894
Olympus Guard Station	14.2	194	4,720
Lunch Lake	14.5	282	3,136
Honeymoon Meadows	16.3	741	2,004
Elk Lake	16.9		
Hoh Lake	16.9	464	769
Stoney Point	18.8	98	1,954
Hayes Guard Station	26.5	247	946
Low Divide	27.4	679	934

TABLE 4. Kendall rank correlation coefficients (r) associating the total area trampled-bare of plant cover at lowland camping locations with the number of social trails, percent forest overstory, and the percent of surface gravel (coarse fraction). s = significance level; N = 101 campsites.

Camp name	No. social trails r	s	Percent overstory r	s	Percent gravel r	s
Sand Point	.32	.01	-.36	.003		
Olympus Guard Station	.47	.01	.32	.08	-.42	.04
Lillian Shelter	.43	.05	.11	.59		
Elkhorn Guard Station	-.18	.71				
Stoney Point	.72	.04	.75	.04		
Horse Flats	.82	.20	.82	.20		
Tipperary Camp	.82	.20	1.00	.04		
Hayes Guard Station	.85	.008	.37	.14		
Honeymoon Meadows	.41	.08	.81	.001	-.33	.16

TABLE 5. Kendall rank correlations coefficients (r) associating the the total area trampled-bare of plant cover at subalpine camping locations with the number of social trails, percent forest overstory, and the percent surface gravel (coarse fraction). s = significance level; N = 114 campsites.

Camp name	No. social trails		Percent overstory		Percent gravel	
	r	s	r	s	r	s
Flapjack Lakes	.28	.19	.19	.37		
Morganroth Lake	.66	.002	.43	.32		
Lunch Lake	.56	.001	.47	.005		
Deer Lake	.47	.001	.31	.019	.19	.15
Hoh Lake	.58	.006	.25	.21	-.014	.95
Clear Lake	.41	.24	.41	.24		
Lake Constance	.53	.008	-.37	.07	.66	.008
Anderson Pass	.69	.05	.59	.09	.58	.10

parameters on a more extensive scale than can be obtained at present. With this knowledge, we conclude that the timely priority in the immediate future is to improve site protection and restoration actions at individual camping areas, rather than a continuing search for some elusive "carrying capacity." There is a need, however, for further research in the development and testing of optimal-use hypotheses at individual camping areas.

LITERATURE CITED

BELL, L. K. and L. C. BLISS. 1973. Alpine disturbance studies: Olympic National Park, U.S.A. Biol. Cons. 5:25-32.

DALE, D. 1973. Effects of trail use under forest in the Madison Range, Montana. M.S. Thesis, Montana State University, Bozeman.

HENDEE, J. C., R. N. CLARK, D. WOOD, M. HOGANS and R. KOCH. 1976. Code-A-Site: a system for inventory of dispersed recreational sites in roaded areas, back country and wilderness. USDA For. Serv. Res. Pap. PNW-209, 33 p., illus. Pacific NW Forest and Range Exper. Station, Portland, Oregon.

LIDDLE, M. J. 1975. A selective review of the ecological effects of human trampling on natural ecosystems. Biol. Cons. 7:17-36.

SCHREINER, E. S. 1974. Vegetation dynamics and human trampling in three subalpine communities of Olympic National Park, Washington. M.S. Thesis, University of Washington, Seattle. 150 pp.

SPEIGHT, M. C. 1973. Outdoor recreation and its ecological effects. Discussion Pap. in Conserv., No. 4, University College, London. 35 pp.

VISITOR IMPACT ON SUBALPINE MEADOW VEGETATION IN GLACIER NATIONAL PARK, MONTANA

Ernest Hartley[1]

Glacier National Park, encompassing more than 400,000 hectares of rugged Rocky Mountain terrain, straddles the Continental Divide in northwestern Montana. People have become an important part of the ecosystem dynamics in the high mountain regions of the park. This research was conducted to determine the nature and degree of disturbance to alpine and subalpine plant communities as a result of human activities.

More than 28,000,000 people have visited Glacier National Park since 1910 when the area became a National Park; about half of this number have visited the Park during the last ten years. Of the areas near treeline, Logan Pass receives the most visitors. About 1.5 million people visit the Park each year.

The effects of people on vegetation and soils are intensified by the non-random patterns of visitation. Deep snows that hold alpine and subalpine plants in dormancy, also close the Going-to-the-Sun Road. Therefore, periods of greatest visitor use occur during July and August coinciding with the Logan Pass growing season. Figure 1 shows that weekends and midday are also periods of peak visitor density. Such compression of heavy visitation into mid-summer interferes with normal plant growth and development in localized areas. Visitor impact was influenced by the total number of people visiting Logan Pass, but more specifically by the size of groups and by their tendencies to stay on trails.

Single individuals walking through dry meadow vegetation at Logan Pass generally leave imperceptible traces, but small groups of people walking in single file do leave a path of crushed plants. Such innocent activity need have only temporary affects on the vegetation; the trampled plants would undoubtedly recover the following year. The problem lies in the high probability that once people create a path, others will retrace it. Such a problem is intensified in heavily visited areas. A new path was created near the Logan Pass Visitor Center in July, 1969. It was again observed in July, 1973 and was a well established path. Other new paths were also created in the Logan Pass area during the study period.

Experimental plots, receiving controlled numbers of trampling treatments, showed that a single trampling treatment per week created, by the end of the growing season, a 9% reduction in natural vegetation cover. Five tramplings per week reduced cover 31%, and fifty tramplings per week reduced cover 85% by the end of the growing season. The overall mean loss of cover was 3.2% per weekly trampling treatment. This means that a plot of dry meadow vegetation trampled by ten people each week would have, at the end of the season, about 32% less vegetational cover than an area not trampled (Figure 2).

The above data are measures of the total vegetational cover of all species. They do not take into account species composition or individual species cover in the treatment plot communities. Vegetational analyses showed that certain species died or disappeared after trampling commenced and did not return even after six years of recovery. These species included *Phyllodoce empetriformis*, *Deltoidium alpinum* var. [illegible], and *Phlox resedifolius*. Nine year recovery data could not be obtained in the summer of 1976 because of grizzly bear activity in the study area. Ten year recovery data will be collected in 1977.

Erythronium grandiflorum appeared to be one of the species most sensitive to human impact. Its shoots died back rapidly when trampled, but in the years that followed, *Erythronium* shoots returned; their survival being facilitated by bulbs and roots deeply set into the soil and thus avoiding physical destruction by trampling. *Claytonia lanceolata* exhibited a similar pattern. Shallow, fibrous-rooted species were generally at a decided disadvantage in this respect. Other species, particularly graminoids, such as *Carex nigricans*, *Carex tolmiei*, and *Phleum alpinum*, were observed to have increased cover in trampled plots six years after their first trampling treatments.

The disappearance of some species and the cover increase of other species created vegetational changes in disturbed sites at Logan Pass. Comparable results were obtained from plot studies as well as from trail-side sampling data. A compilation of about 10,000 point quadrat sampling points gathered along Logan Pass trails provided data for measuring the relative sensitivity of species to trail-side impact. Data from 94 ten-meter transects run perpendicularly to trails provided mean cover values for each species along the trail-side trampling gradient. Least squares regression equations were calculated for each species. The linear regression lines were then plotted as seen in Figures 3 and 4. Figure 4 simply expands the 0 to 10 portoin of the "y" axis in Figure 3. Species symbols, regression equations, and significance of correlation coefficients for each species are included in Table 1.

Based on the array of regression lines to be found at one meter and at ten meters from the center of a heavily used trail in the dry meadow community. A comparison of these two lists shows that the community at 1 m had 13% fewer species than the community at 10 m, and there were 44% more rare species in the 10 m community than at 1 m (rare species are defined as species with cover of less than 1% of total plant cover).

Table 1, using the same trail-side transect data, ranks each species according to its relative sensitivity to trampling. Sensitivity is based on a Sensitivity Index defined as the percent difference in the number of sampling points for a species between 10 m and 1 m as determined by a least squares linear regression equation calculated from 94 transects of sampling data. According to this measure, 35 species were found to decrease toward the trail and were thus interpreted to be relatively sensitive to trampling. Seven species increased toward the trail and were interpreted to be relatively resistant to trampling or even favored by it. There were fewer species, loser species diversity, and less total vegetational cover in communities at 1 m from the trail than at distances of 10 m from trails in this pooled set of data.

A general characteristic of disturbed communities, when compared to those that are stabilized,

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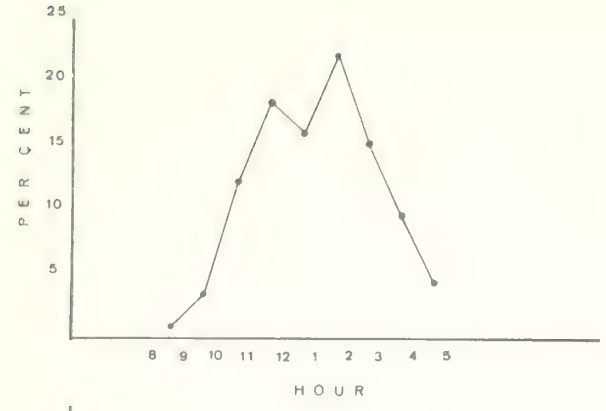

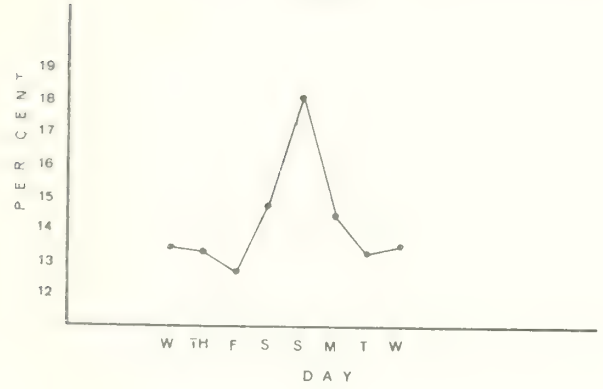

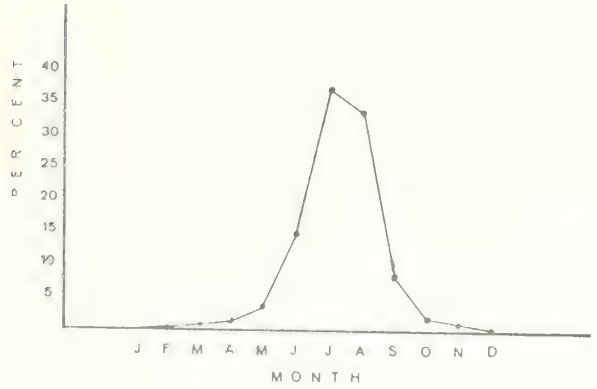

FIGURE 1. Mean percentage distribution of daily, weekly, and monthly visitors in Glacier National Park. (top) Daily distribution of hikers on Hidden Lake Trail at Logan Pass. Each data point is the percentage of the total mean day visits. (middle) Weekly distribution of visitors to Glacier National Park. Each data point is the percentage of the mid-summer mean week total. (bottom) Monthly distribution of visitors to Glacier National Park. Each data point is the percentage of the mean annual total visitation.

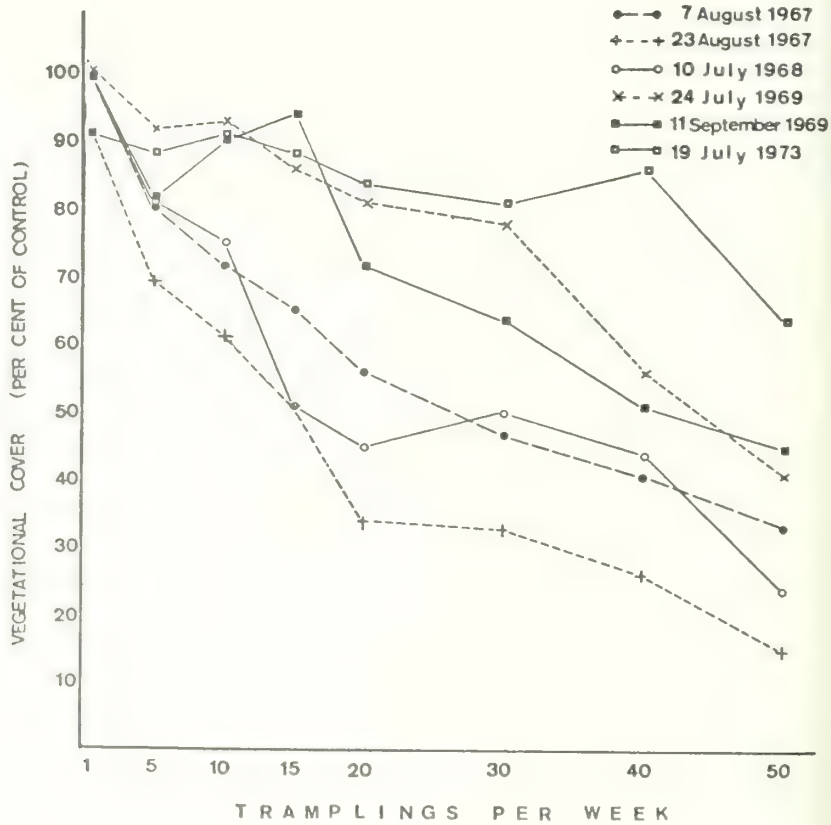

FIGURE 2. Vegetational cover as a function of trampling intensity in experimental plots from 1967 (where first trampled) to 1973.

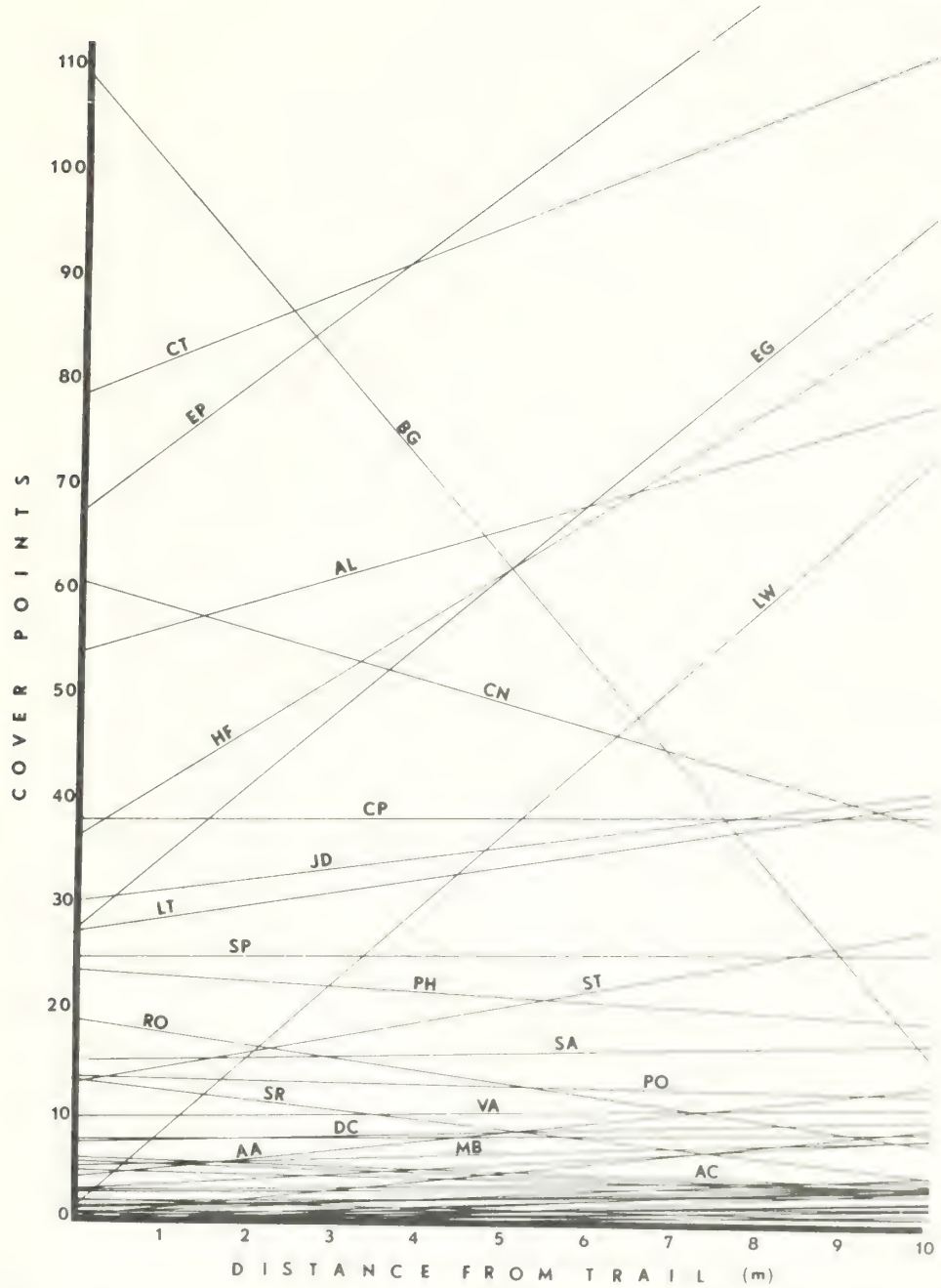

FIGURE 3. Regression lines of total cover for trail-side species. Each line plots the least squares linear regression line of plant cover for a species based on 94 ten-meter transects placed perpendicular to trail axes. Species symbols, regression equations, and significance of correlation coefficients for each species are included in Table 1. The y axis, for the scale 0-10, is expanded in Figure 4 for better line resolution.

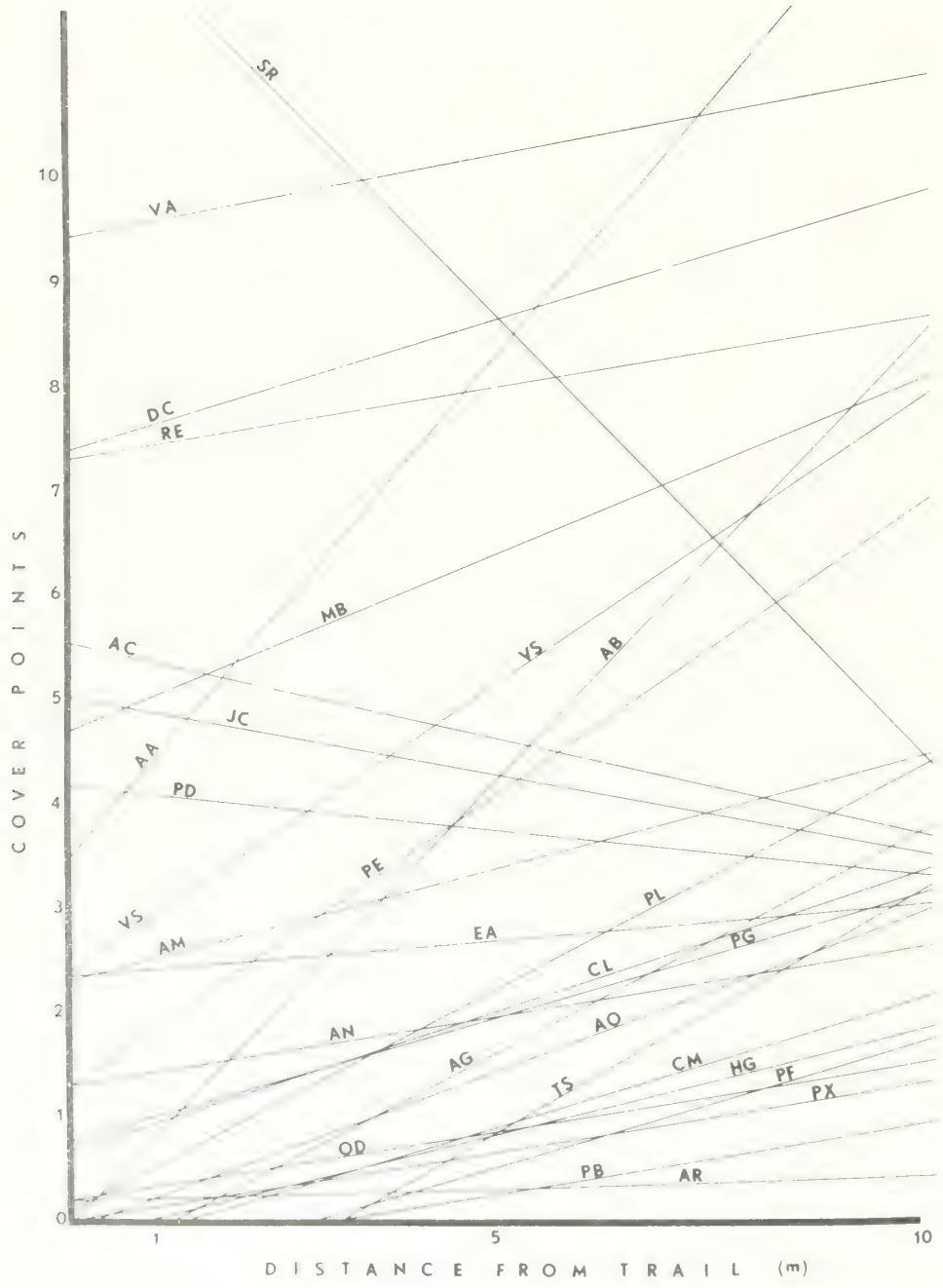

FIGURE 4. Regression lines of total cover for trail-side species. See Figure 3 for explanation.

TABLE 2. Index of relative sensitivity to trampling.

Species	Symbol	Sensitivity[1] Index	Cover Difference[2]	Regression[3] Equation	Correlation[4] Coefficient
Pedicularis bracteosa	PB	-100.0%	1.3	Y = - 0.47 + 0.14X	+.6275***
Trisetum spicatum	TS	-100.0%	4.1	Y = - 1.53 + 0.46X	+.7890***
Parnassia fimbriata	PF	-100.0%	2.2	Y = - 0.73 + 0.24X	+.5740***
Castilleja miniata	CM	-100.0%	2.2	Y = - 0.33 + 0.24X	+.6888***
Agrostis thurberiana	AG	-100.0%	3.8	Y = - 0.53 + 0.42X	+.5525***
Hieracium gracile	HG	-100.0%	1.8	Y = - 0.20 + 0.20X	+.6084***
Polytrichum spp.	PX	- 94.7%	1.3	Y = - 0.07 + 0.14X	+.5145***
Anemone occidentalis	AO	- 92.2%	2.7	Y = - 0.07 + 0.30X	+.4783***
Abies lasiocarpa	AB	- 90.0%	7.6	Y = - 1.87 + 1.03X	+.6488***
Luzula wahlenbergii	LW	- 88.9%	65.9	Y = + 0.93 + 7.32X	+.9660***
Phyllodoce glanduliflora	PL	- 87.8%	3.8	Y = - 1.07 + 0.54X	+.7663***
Oxyria digyna	OD	- 78.0%	1.2	Y = + 0.20 + 0.13X	+.3955***
Phyllodoce empetriformis	PE	- 74.1%	5.0	Y = + 1.20 + 0.56X	+.6449***
Claytonia lanceolata	CL	- 73.6%	2.4	Y = + 0.60 + 0.27X	+.5121***
Pedicularis groenlandica	PG	- 69.4%	2.2	Y = - 1.40 + 0.45X	+.8185***
Arnica alpina	AA	- 65.9%	8.6	Y = + 3.47 + 0.95X	+.6354***
Erythronium grandiflorum	EG	- 64.0%	61.7	Y = + 27.80 + 6.85X	+.7225***
Valeriana sitchensis	VS	- 62.3%	4.9	Y = + 2.40 + 0.54X	+.5841***
Hypericum formosum	HF	- 53.9%	47.3	Y = + 35.20 + 5.25X	+.7131***
Senecio triangularis	ST	- 47.4%	13.2	Y = + 13.20 + 1.47X	+.5568***
Antennaria alpina	AN	- 45.5%	1.2	Y = + 1.27 + 0.13X	+.2950**
Arnica cordifolia	AR	- 45.0%	0.2	Y = + 0.20 + 0.02X	+.0896 ns
Achillea millefolium	AM	- 43.2%	1.9	Y = + 2.27 + 0.21X	+.2240*
Erigeron peregrinus	EP	- 43.1%	55.7	Y = + 67.27 + 6.19X	+.6346***
Mitella breweri	MB	- 37.3%	3.0	Y = + 4.67 + 0.33X	+.3114**
Arnica latifolia	AL	- 34.0%	26.6	Y = + 48.67 + 2.95X	+.4768***
Litter	LT	- 29.6%	11.9	Y = + 26.93 + 1	+.5613***
Carex tolmiei	CT	- 27.9%	31.3	Y = + 77.53 + 3.48X	+.3672***
Juncus drummondii	JD	- 24.8%	10.3	Y = + 29.93 + 1.14X	+.3450***
Deschampsia caespitosa	DC	- 22.0%	2.2	Y = + 7.40 + 0.24X	+.2156*
Epilobium alpinum	EA	- 20.8%	0.6	Y = + 2.33 + 0.07X	+.1351 ns
Ranunculus eschscholtzii	RE	- 13.7%	1.2	Y = + 7.27 + 0.13X	+.1077 ns
Veronica alpina	VA	- 13.2%	1.4	Y = + 9.33 + 0.16X	+.1238 ns
Salix alpina	SA	- 12.2%	2.1	Y = + 14.73 + 0.23X	+.1149 ns
Carex phaeocephala	CP	- 2.5%	1.0	Y = + 38.00 + 0.11X	+.0359 ns
Sibbaldia procumbens	SP	- 1.4%	0.4	Y = + 25.47 + 0.04X	+.0127 ns
Poa alpina	PO	+ 5.8%	0.7	Y = + 13.13 - 0.08X	-.0765 ns
Phleum alpinum	PH	+ 19.2%	3.7	Y = + 23.33 - 0.41X	-.3303***
Potentilla diversifolia	PD	+ 21.6%	0.7	Y = + 4.13 - 0.08X	-.1479 ns
Juncus castaneus	JC	+ 38.6%	1.4	Y = + 5.00 - 0.15X	-.1933*
Arenaria capillaris	AC	+ 44.1%	1.6	Y = + 5.47 - 0.18X	-.2136*
Carex nigricans	CN	+ 54.3%	20.7	Y = + 61.13 - 2.30X	-.3877***
Rock	RO	+142.4%	10.4	Y = + 17.67 - 1.05X	-.5626***
Senecio resedifolius	SR	+163.5%	7.5	Y = + 12.87 - 0.83X	-.6932***
Bare ground	BG	+516.7%	83.3	Y = +108.73 - 9.26X	-.6214***

1. Sensitivity Index is defined as the percentage decrease (top of table) or increase (bottom of table) of sampling points between the 10 m point (control) and the 1 m point (treatment) from the trail median. It is determined from a least squares linear regression equation calculated from 94 transects of sampling data.

2. The actual sampling point difference, or cover difference, between the 10 m and 1 m points on the regression line calculated from 94 transects.

3. The regression equations are in the form, $y = a+bx$, in which "x" is the distance from the trail median, "y" is the total species cover from 94 transects, "a" is the regression line's point of interception on the "y" axis, and "b" describes the slope of the regression line.

4. Correlation coefficients are given with levels of significance as measured by a *t*-test; *P = 0.05, **P = 0.01, ***P = 0.001, and ns = not significant at 0.05 level.

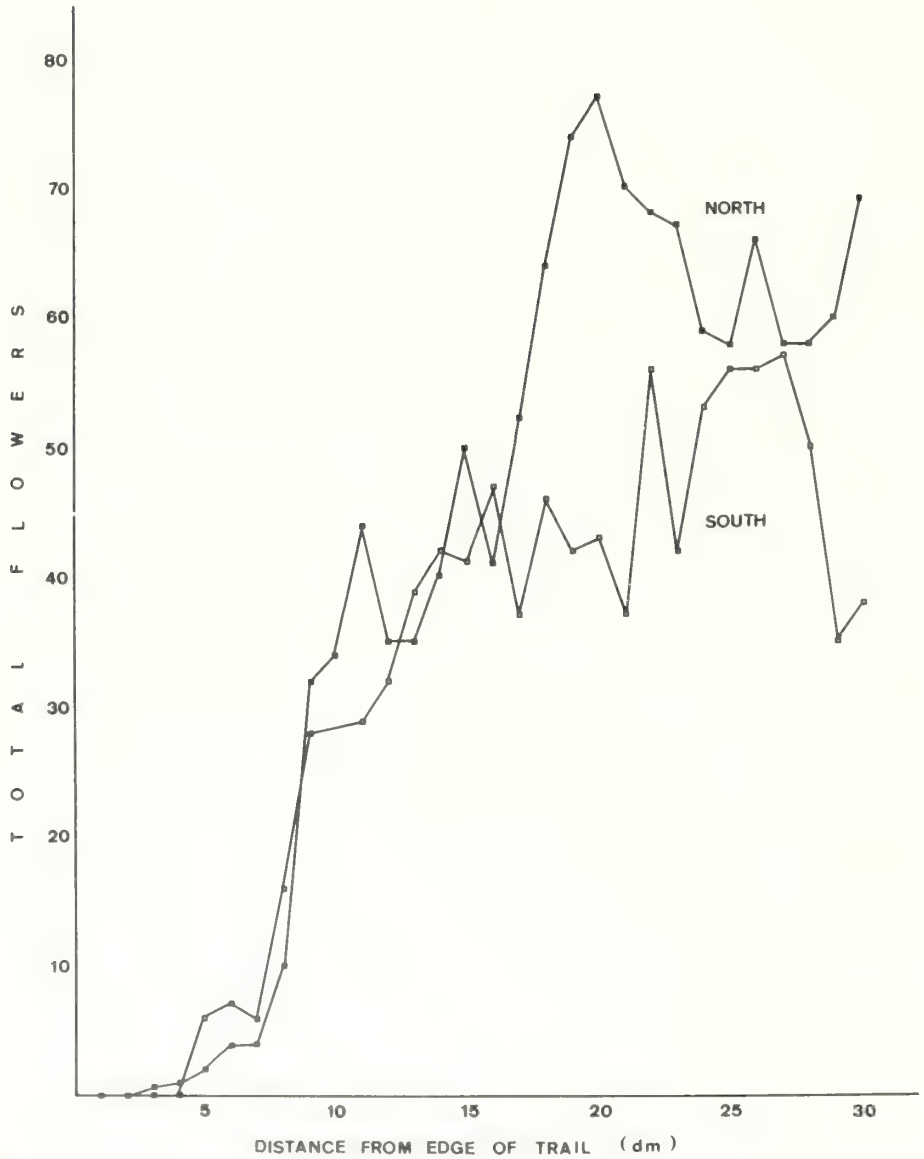

FIGURE 5. Trail-side distribution of *Erythronium grandiflorum* (glacier lily) flower density near Logan Pass on the Going-to-the-Sun Road on 15 July 1969.

TABLE 2

TOTAL UTILIZABLE CARBOHYDRATE, RELATIVE COVER, FLOWERING DENSITY AND HEIGHT OF ERYTHRONIUM GRANDIFLORUM ALONG PATH AND IN PLOT 2 AT LOGAN PASS

Characteristic	Distance from Trail: More than 2 m	Distance from Trail: Less than 0.5 m	Per cent Reduced
Total Utilizable Carbohydrates 7 August 1969 n = 3	35.1%	29.5%	(-16%)
Relative Cover 18 July 1969 n = 750	16.8 $\bar{+}$ 1.9%	10.4 $\bar{+}$ 5.4%	(-38%)
Flower Density (flowers/dm^2) 17 July 1969 n = 1000	0.50 $\bar{+}$ 0.07	0.19 $\bar{+}$ 0.12	(-62%)

	Plot 2: Subplot 1 (T-0, C-0)	Plot 2: Subplot 9 (T-50, C-2)	
Total Utilizable Carbohydrates 13 July 1969 n = 2	43.5%	29.9%	(-31%)
Relative Cover 12 July 1969 n = 200	23.0%	8.0%	(-65%)
Flower Density (flowers/dm^2) 5 July 1969 n = 100	0.58	0.0	(-100%)
Height of Plants (cm) 6 July 1969 n = 20	11.5	5.9	(-50%)

is that they are often dominated by a small number of very common species. Stabilized communities generally contain a higher number of species that more equally share the available space. Figure 4 illustrates such a characteristic; the more disturbed community at 1 m has a greater spread in species cover values than the 10 m community. The convergence of regression lines toward the latter bears out this conclusion.

The distance from the trail's edge through which there were measurable effects of human impact depended upon the parameter being studied, the sensitivity of the measurement, local trail conditions, and the intensity of human trampling, not only at present, but in the past as well. The mean distance from the center of the trail to natural vegetational cover, irrespective of species composition, was about 3 m. However, the transect distance over which there was a distinct increase in the number of species and an increase in Shannon-Weiner Diversity Indices was about 5 m. Eight of the more common species reached their maxiumum cover between 4 and 8 m from the trail.

The above pieces of evidence suggest that most visitor impact is restricted to the first five meters from the center of trails at Logan Pass. The sampling data of individual species suggests, however, that some species are responding to a trampling gradient more than 5 m in length along many of the more heavily used paths in this area.

The effect of trampling on flower and inflorescence production was studied along well used trails and in experimentally trampled plots. Without exception, reproductive potential of all flowering plant species was reduced by trampling treatments in experimental plots. Visual observations, that flowering was also inhibited at trail-side was generally supported by sampling data, although a few species had higher flower densities at trail-side than at distances of two or three meters from the trail. This apparent contradiction with plot data is explained by taking into account the fact that vegetation along the margins of paths has received neither the known amounts of trampling treatments nor the same patterns of trampling through time. Some trail margin vegetation was being heavily trampled at the time of sampling; others were perhaps in some stage of recovery following heavy trampling, some graminoid species tended to increase in prominence as they invaded areas left barren by the disappearance of more trampling sensitive species.

Trail-side flower density counts of *Erythronium grandiflorum* were made along a much used path near Logan Pass on the Going-to-the-Sun Road. One by three meter transects were run perpendicular to the path. The results of thirty such transects indicate that the number of *Erythronium* flowers increases away from the trail over the first 1.8 m from the edge of the trail (Figure 5). Other trail-side flower count data show that the zone of disturbance varies with the location and the amount of off-trail foot traffic. In disturbed situations, such as in the dry meadow paths at Logan Pass, reproductive potential was retarded within a mean distance of 1.7 m from the edge of trails.

Non-structural carbohydrate reserves in the roots and underground storage organs of *Erythronium grandiflorum* were analyzed to find a possible explanation for the smaller plants, decreased flower production, and lower plant diversity observed in trampled sites. Differences, significant at the 1% level, were observed in the total utilizable carbohydrate content of root and bulb samples collected within one-half meter from the edge of trails when compared to samples collected at distances greater than two meters from the trail. Table 2 illustrates the differences observed between trampled and control sites at trail-side and in experimental plots. In each, a 1 x percentage decrease in carbohydrate content was associated with a 2 x percent decrease in relative cover, and a 3 x percent decrease in flower density.

The effects of walking on alpine and subalpine plants seems to occur first through physical damage to their aerial portions. This not only damages tissue of the current year's plant, but also lowers the plant's ability to prepare for overwintering and early growth the following year. Thus, the secondary effects of trampling seem to be a decrease of energy flow through the plant initiated by the loss of photosynthetic tissue. As a consequence, decreased levels of utilizable (or non-structural) carbohydrates are produced and result in smaller plants and less reproductive potential the following year. If plants are further trampled while in this depressed condition the result may be continued breakdown of the system and death of the plant.

It is the attrition of trampling-sensitive plants that accounts for the changes in floristic composition and vegetational relationships observed along trails. Certain trampling-resistant plants do invade the spaces thus provided, if the intensity of off-trail walking is not too severe. The extensive areas of bare ground that have occurred at Logan Pass and other high mountain areas is evidence that trampling pressure has exceeded the resistance of all species, including *Carex nigricans*, the species found to be the most resistant to human trampling.

People are an unnatural part of high mountain ecosystems. The biota has evolved largely in the absence of man, and it is principally in relationship to man that alpine and subalpine plants are considered fragile. Such plants are well adapted to the severe physical environment of their habitat, but not to the activities of large numbers of people.

Man-induced instability in high mountain ecosystems is best avoided by keeping people out of them, but if this is impossible, then it becomes of paramount importance to keep people on trails. This is most successfully accomplished by proper use of signs, National Park Service supervision, and well made and maintained trails designed to accommodate the existing levels of human traffic.

REFERENCE

HARTLEY, ERNEST. 1976. Man's effects on the stability of alpine and subalpine vegetation in Glacier National Park, Montana. Ph.D. Dissertation, Duke University, Durham, North Carolina 258 pp.

VISITOR USE IMPACT IN A SUBALPINE MEADOW, YOSEMITE NATIONAL PARK, CALIFORNIA

John Lemons[1,2]

INTRODUCTION

It has been proposed that management of national parks and wilderness areas be based upon the concept of ecological carrying capacities (Burden and Randerson 1972). An ecological carrying capacity as it relates to human use of an area is the level of impact which may be tolerable without exceeding the physical and biotic capacity of the ecosystem to regenerate itself. Since ecosystem destruction which exceeds carrying capacity levels results in dsiruption of ecological processes and destruction of ecosystem structure, it is important that land resource managers develop carrying capacity models useful in the maintenance of human visitor populations well below that of an area's carrying capacity.

Relatively little attention has been given to the application of numerical methods of vegetation analysis to applied problems of land management and use in national parks. Such methods are, however, of considerable value for predicting for future trends of condition based upon existing or future types and intensities of uses. Ideally, to be of maximum value to land resource managers, applied numerical methods of vegetation analysis should be possible on a minimum of data and by a simple technique. The reason for this is two-fold. First, many resource managers lack necessary funding to undertake extensive and elaborate studies. Second, past, current, and anticipated future recreation pressures and the resultant ecological effects are forcing many resource managers to make carrying capacity-related decisions on available data which are often insufficient. Thus an urgent need exists for simple techniques which yield useful and rapid data. Hopefully, the techniques would assure that a land resource manager in the field can assign a community stand to existing groups of stands from his own resources, thereby achieving prediction ability.

Many studies have proved helpful to land resource managers in the decision-making process, although the information obtained has not always been of predictive value. For example, Burden and Randerson (1972) studied the nature of the changes caused by human trampling in the soils and ground of semi-natural areas, discussed quantitative methods for relating these changes to the intensity of use, and suggested how data might be applied in the formulation of management policies for recreation areas. They found that some species of plants had significant negative correlation with trampling pressure. Other species showed no correlation with trampling pressure. Some species showed changes in levels of significance when environmental factors such as changes in soil moisture and light intensity were considered. They demonstrated that species possess a complex relationship involving both trampling and one or more environmental factors with trampling intensity and were too complex to be adequately analyzed.

Dale and Weaver (1974) presented results showing a correlation between trail width and numbers of users, and how the vegetation complex adjacent to trails is modified by visitor use. They provided lists of species whose frequencies increased, decreased, or showed no change as a function of distance from a trail. While all of the increaser and decreaser species show qualitative correlation with distance from the trail, only a few of these species exhibited significant quantitative correlations. Also, some species had frequency values of zero for some study sites and were therefore not suitable for correlation measurements.

Willard and Marr (1970) related alpine vegetation destruction to types of visitor activities in a national park and discussed the variable responses of different ecosystems to use. Visitor effects were categorized into discreet classifications ranging from no effect to virtual destruction of the ecosystem. This study provided a qualitative assessment of visitor use impact to the ecosystem.

The above mentioned studies are typical of others and indicate that although some species respond in a systematic manner to trampling stress and can therefore be used in quantitative predictions, most species are variable in their response to trampling stress and do not demonstrate high fidelity for a given level of use. Therefore, most species can be used only as qualitative indicators of ecosystem change. These studies, and others (Schofield 1967; LaPage 1967; Wager 1964) shared the technique of relating trampling intensity to observed effects such as the elimination of a particular species or a reduction of a particular species' attribute (e.g., cover). The studies did not assess community attributes.

This paper presents results which show, for a subalpine meadow of the central Sierra Nevada of California, how simple and standard methods of vegetation analysis on a community basis (rather than individual species) may yield a correlation with human trampling impact. Such a correlation may then be used by land resource managers to predict the effects of trampling on the ecosystem. It is also shown that for predictive purposes, it may be better to use community instead of individual species attributes, as has been done in most studies, when attempting to correlate response with visitor use. Since all data have not been analyzed, this paper is of a preliminary nature.

METHODS

In order to determine whether correlations exist between vegetation condition and consequence of trail use (soil compaction), existing vegetative stands within the same homogeneous vegetative community but with different levels of human use were selected for study. Floristic composition and soil compaction were assumed to be determined principally by the particular intensity of trampling at each site. This was thought to be a valid assumption for the following reasons. First, soil compaction has been shown to relate to intensity of trampling (Burden and Randerson 1972); Chappell et al. 1971). Second, the correlation coefficients for attributes of many, although not all, species with soil compaction have been shown to be relatively insensitive to exclusion of certain environmental effects such as soil depth, conductivity, moisture, and pH (Burden

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[2]Paper presented at the Conference by F. Owen Hoffman, Oak Ridge National Laboratory, Tennessee

TABLE 1. SPECIES ATTRIBUTE VALUES AND SOIL COMPACTION

Stand No.		1	2	3	4	5	6	7	8
Relative Soil Compaction*		0.25	0.27	0.42	0.44	0.46	0.53	0.63	1.00
Species									
Oryzopsis Kingii	**c	50.6	40.5	48.1	23.7	45.7	1.2	2.8	0.0
	d	20.9	18.7	19.9	15.8	17.9	0.8	1.8	0.0
	f	100.0	90.6	93.8	90.6	87.5	15.6	25.0	0.0
	I.V.	1.0	0.9	0.9	0.8	0.9	0.1	0.2	0.0
Antennaria alpina media	c	12.9	21.5	7.5	16.6	18.8	24.8	1.0	0.0
	d	20.3	35.4	14.6	18.7	30.8	14.1	0.8	0.0
	f	93.8	96.9	71.9	81.3	93.8	53.1	9.4	0.0
	I.V.	0.8	1.0	0.6	0.8	0.9	0.6	0.1	0.0
Trifolium monanthum	c	12.0	2.1	7.7	6.6	6.6	6.3	0.3	0.0
	d	12.5	3.0	14.3	11.4	12.5	7.4	0.6	0.0
	f	40.6	9.4	81.3	90.6	56.3	62.5	15.6	0.0
	I.V.	0.6	0.1	1.0	1.0	0.7	0.7	0.2	0.0
Solidago multiradiata	c	5.1	8.7	5.4	7.0	2.8	0.6	0.0	0.0
	d	6.0	9.9	7.6	7.1	2.5	0.7	0.0	0.0
	f	31.3	31.3	53.1	65.6	25.0	6.3	0.0	0.0
	I.V.	0.5	0.6	0.8	1.0	0.4	0.1	0.0	0.0
Carex exserta	c	1.4	6.8	6.8	10.7	6.3	17.4	65.1	0.0
	d	1.2	8.1	13.1	14.0	5.2	30.5	73.0	0.0
	f	15.6	37.5	78.1	65.6	62.5	68.8	100.0	0.0
	I.V.	0.1	0.2	0.3	0.4	0.4	0.5	1.0	0.0
Aster alpina	c	3.7	2.4	11.2	15.2	1.5	0.0	0.4	0.0
	d	3.8	2.6	13.1	14.5	2.1	0.0	0.1	0.0
	f	31.3	25.0	71.9	71.9	18.8	0.0	3.1	0.0
	I.V.	0.4	0.3	0.9	1.0	0.2	0.0	0.0	0.0
Penstemon oreocharis	c	2.3	2.8	2.7	9.5	7.3	4.6	5.9	0.0
	d	1.4	2.4	4.0	7.7	8.1	4.6	6.0	0.0
	f	21.9	15.6	31.3	65.6	62.5	37.5	43.8	0.0
	I.V.	0.3	0.3	0.5	1.0	0.9	0.6	0.7	0.0
Polytrichum sp.	c	2.1	3.6	0.0	0.0	1.9	1.2	0.0	0.0
	d	3.7	5.0	0.0	0.0	6.6	2.5	0.0	0.0
	f	34.4	34.4	0.0	0.0	15.6	15.6	0.0	0.0
	I.V.	0.9	1.0	0.0	0.0	0.6	0.4	0.0	0.0
Microseris nutans	c	1.5	3.0	0.8	0.1	0.3	0.0	0.5	0.0
	d	2.0	3.0	0.9	0.1	0.2	0.0	0.4	0.0
	f	21.9	25.0	6.3	3.1	3.1	0.0	6.3	0.0
	I.V.	0.8	1.0	0.3	0.1	0.1	0.0	0.2	0.0
Gentiana bolopetala	c	1.0	1.9	0.7	0.8	1.8	0.8	0.2	0.0
	d	1.1	1.7	1.6	0.7	2.1	0.8	0.4	0.0
	f	12.5	21.9	21.9	18.8	31.3	12.5	9.4	0.0
	I.V.	0.4	0.7	0.7	0.6	1.0	0.4	0.3	0.0
Pedicularis attolens	c	2.1	3.6	1.1	1.9	0.0	3.9	0.0	0.0
	d	2.3	0.6	1.2	1.3	0.0	2.0	0.0	0.0
	f	28.1	9.4	18.8	18.8	0.0	34.4	0.0	0.0
	I.V.	0.8	0.3	0.5	0.5	0.0	1.0	0.0	0.0

TABLE 1. SPECIES ATTRIBUTE VALUES AND SOIL COMPACTION (Continued)

Stand No.		1	2	3	4	5	6	7	8
Relative Soil Compaction*		0.25	0.27	0.42	0.44	0.46	0.53	0.63	1.00
Species									
Rumex angiocarpus	c	0.8	2.0	0.5	0.6	1.1	3.9	0.1	0.0
	d	1.7	5.2	0.9	0.8	3.4	4.4	0.1	0.0
	f	31.3	50.0	18.8	18.8	34.4	50.0	3.1	0.0
	I.V.	0.6	1.0	0.3	0.3	0.7	1.0	0.1	0.0
Luzula sp.	c	0.4	1.7	0.3	4.5	2.4	1.5	0.6	0.0
	d	0.5	1.1	0.3	5.0	3.6	2.3	0.2	0.0
	f	6.3	18.8	6.3	50.0	31.3	25.0	3.1	0.0
	I.V.	0.1	0.4	0.1	1.0	0.6	0.5	0.1	0.0
Danthonia unispicata	c	1.4	0.0	4.9	0.6	0.0	0.2	0.3	0.0
	d	0.6	0.0	5.0	0.4	0.0	0.2	0.2	0.0
	f	9.4	0.0	37.5	9.4	0.0	3.1	3.1	0.0
	I.V.	0.2	0.0	1.0	0.2	0.0	0.1	0.1	0.0
Muhlenbergia filiformis	c	0.0	0.6	1.5	2.1	0.7	27.5	22.5	0.0
	d	0.0	1.7	2.0	2.3	0.9	28.5	16.2	0.0
	f	0.0	12.5	25.0	28.1	6.3	96.9	84.4	0.0
	I.V.	0.0	0.1	0.2	0.2	0.1	1.0	0.8	0.0
Mimulus primuloides	c	1.5	0.4	0.2	0.1	2.7	0.1	0.3	0.0
	d	3.7	0.4	0.6	0.1	4.1	0.2	0.1	0.0
	f	6.3	6.3	12.5	3.1	31.3	3.1	3.1	0.0
	I.V.	0.3	0.2	0.4	0.1	1.0	0.1	0.1	0.0
Ivesia lycopodioides	c	0.9	0.5	0.4	0.2	0.0	0.0	0.0	0.0
	d	0.9	0.6	0.6	0.2	0.0	0.0	0.0	0.0
	f	12.5	6.3	12.5	6.3	0.0	0.0	0.0	0.0
	I.V.	1.0	0.5	1.0	0.5	0.0	0.0	0.0	0.0
Stipa sp.	c	0.0	0.9	0.0	0.0	0.0	0.0	0.0	0.0
	d	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0
	f	0.0	3.1	0.0	0.0	0.0	0.0	0.0	0.0
	I.V.	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0,0
Ophioglossum sp.	c	0.1	0.1	0.0	0.0	0.0	0.2	0.0	0.0
	d	0.3	0.4	0.0	0.0	0.0	0.2	0.0	0.0
	f	6.3	6.3	0.0	0.0	0.0	3.1	0.0	0.0
	I.V.	1.0	1.0	0.0	0.0	0.0	0.5	0.0	0.0
Deschampsia caespitosa	c	0.4	0.0	0.0	0.0	0.0	5,8	0.0	0.0
	d	17.1	0.0	0.0	0.0	0.0	1.0	0.0	0.0
	f	3.1	0.0	0.0	0.0	0.0	15.6	0.0	0.0
	I.V.	0.9	0.0	0.0	0.0	0.0	1.0	0.0	0.0

*relative soil compaction equals stand soil compaction/soil compaction of most compacted stand (no. 8)

**c = relative cover; d = relative density; f = relative frequency; I.V. = importance value

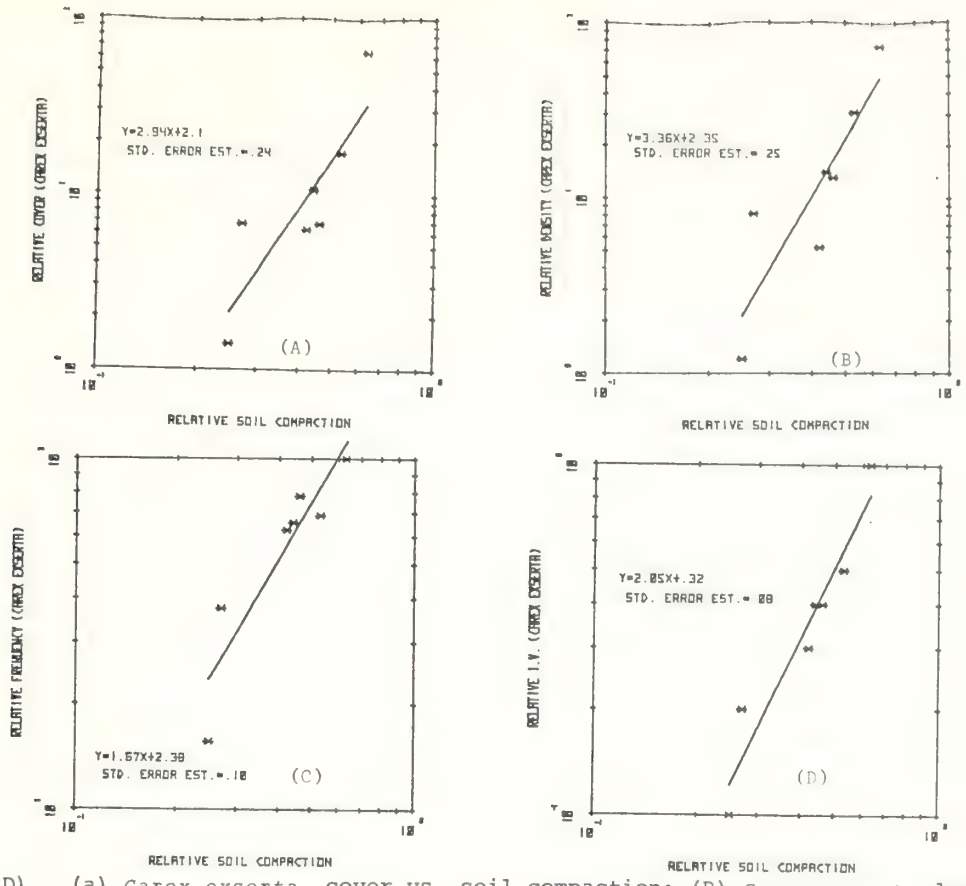

FIGURE 1. (a-D). (a) *Carex exserta* cover vs. soil compaction; (B) *Carex exserta* density vs. soil compaction; (C) *Carex exserta* frequency vs. soil compaction; (D) *Carex exserta* I.V. vs. soil compaction.

TABLE 2. Number of transect sublengths (1 m) in each stand occupied by each species with 5% cover in at least one stand together with X^2 values for 7 X 2 contingency tests.

Species	Stand No. 1	2*	3	4	5	6	7	8	X^2
Oryzopsis Kingii	72	0	12	20	75	70	72	80	299
Antennaria alpina media	65	0	42	8	58	75	78	75	232
Trifolium monanthum	72	0	50	12	65	45	8	32	183
Solidego multiradiata	52	0	5	0	42	20	25	25	123
Carex exserta	52	0	55	80	62	50	30	12	155
Aster alpina	58	0	0	2	58	15	20	25	200
Penstemon oreocharis	52	0	30	35	25	50	12	17	74
Muhlenbergia filiformis	22	0	78	68	20	5	10	0	315
Deschampsia caespitosa	0	0	12	0	0	0	0	2	61

*Stand No. 2 was not included in X^2 calculations since no vegetation was growing within it.

and Randerson 1972). Third, the study site was homogeneous except for trampling pressure (Lemons, in preparation).

The study site was an open alpine meadow (elevation 2630 m) located within Lyell Canyon in Yosemite National Park, California. The predominant human use of the study area has been hiking, with occasional associated stock use. There are currently no data available concerning past or present visitor use of the area, although such data may be available at a future date (van Wagtendonk, pers. comm.)

Measured vegetative attributes for the 20 most common species consisted of frequency, density and cover. Attributes were measured using standard methods (Cain 1959) along 16 m transects with a 1 cm width for each of the eight vegetative stands. The stands existed along a gradient of light to heavy human use. Each stand was sampled at five random sites, and values of the five sites within each stand were averaged for this report. The measured vegetative attributes were later calculated to give relative values, respectively, which were also combined to give importance values (rel. frequency + rel. density + rel. cover = I.V.). The relative vegetative attribute values and importance values were used to arrive at coefficient of community (CC) values so that the similarity of given stands could be compared to an undisturbed reference stand.

The CC was calculated from the respective relative values for frequency, density, cover and importance values from the species list using the relationship

$$CC = 2C\ (A+B)^{-1}$$

where A was the attribute value for species in the undisturbed reference stand, B was the attribute value for species in the trampled stand, and C was the value for the species common to each stand (Greig-Smith 1964). Coefficient of community values comparing undisturbed areas have been used by other investigators for different ecosystems and perturbations (Fraley and Whicker 1973; Woodwell and Rebuck 1967).

Soil compaction was measured by use of a soil penetrometer for each 1 m of transect length (16 times/transect) to a depth of 10 cm. Values were recorded as number of penetrometer impacts and were averaged to give stand values. All data were collected during July and August of 1974 and 1975.

RESULTS AND DISCUSSION

Table 1 shows the relative attribute values for frequency (probability of an occurrence in 1 m sublength), density, cover, and importance values for each species within each stand. Relative soil compaction values for each stand are also shown in Table 1. Species identification was according to Munz (1965). Since the study site was homogeneous, if visitor use patterns within the study area have remained constant for a sufficient time period for the vegetation to come to equilibrium with visitor use effects, the vegetation attribute values and soil compaction should be determined principally by the intensity of trampling at each stand (Burden and Randerson 1972). Under such circumstances, a correlation should therefore exist between vegetative attribute values of the stands and soil compaction.

Data of Table 1 indicate that the species *Muhlenbergia filiformis* and *Carex exserta* increase in attribute values as soil compaction within the stands increase. This is probably due to the fact that they are early successional species with flexible upright growth forms that are resistant to trampling stress. It is likely they do not persist in undisturbed sites because of failure to withstand competition from trampling sensitive species. Lack of persistence in undisturbed sites due to lack of a species competitive ability has been shown for other species in trampled communities (Chappell et al. 1971).

Most other species listed in Table 1 show a reduction of attribute value and I.V. as soil compaction increases. This change in floristic composition suggests that, in the ecological context, the vegetation is reacting to trampling stress by simplification and the selection of a few new dominants.

Nine of the species listed in Table 1 comprised more than 5% of the total cover for at least one stand. The distribution of the nine species was examined, and greater aggregation was found in each case than that expected from a Poisson distribution. This indicated over dispersal or contagious distribution of the species (Greig-Smith 1964). 7X2 contingency tests for association between the nine species and individual stands show highly significant associations ($P < 0.001$) in each case (Table 2).

In order to determine whether individual species attribute values and I.V. were significantly correlated with soil compaction, attribute values and I.V. for each species were regressed on soil compaction values. *Carex exserta* was the only species whose attribute values increased and were significantly (0.05 level) correlated with soil compaction (Figure 1A-D). It should be noted that Figure 1 A-D shows data plotted on a log-log plot for the equation $Y = AB^X+C$. The data also fit a second-order polynomial for a linear-linear plot. However, in the latter case the curve predicts increased attribute values for *C. exserta* for the undisturbed reference stands compared to moderately disturbed stands, probably because of statistical sampling error. Therefore, a polynomial fit was not applied to the attribute data for *C. exserta*.

The remaining species decrease in attribute value as soil compaction increases. However, the decrease is not systematic for an individual species. The absence of systematic trends probably results from the fact that trampling imposes a number of important habitat stresses on a species, including changes in soil compaction, mechanical properties of the soil, soil moisture, light intensity, interspecies competition, and alteration of microclimate (Chappell et al. 1971). Thus species response is to a changing but complex gradient. It appears, therefore, that individual species response may be used only in a qualitative as opposed to a quantitative predictive manner.

The approach used in the present study was to determine whether stand soil compaction could be used for quantitatively predicting community response to trampling, thus providing a measure of deviation of community response from the natural undisturbed condition. Therefore, the community coefficients calculated from vegetative data contained in Table 1 were plotted against the soil compaction values. These plots are shown in Figure 2 (A-D) and indicate the validity of the approach.

For example, soil compaction is seen to correlate with community coefficient values calculated from relative values for frequency, density, cover and importance values, respectively. The choice of which species attribute(s) to use for calculation of community coefficient values is not an obvious one. Individual species response is likely to be indicated by change in any of the relative attribute values used. However, there

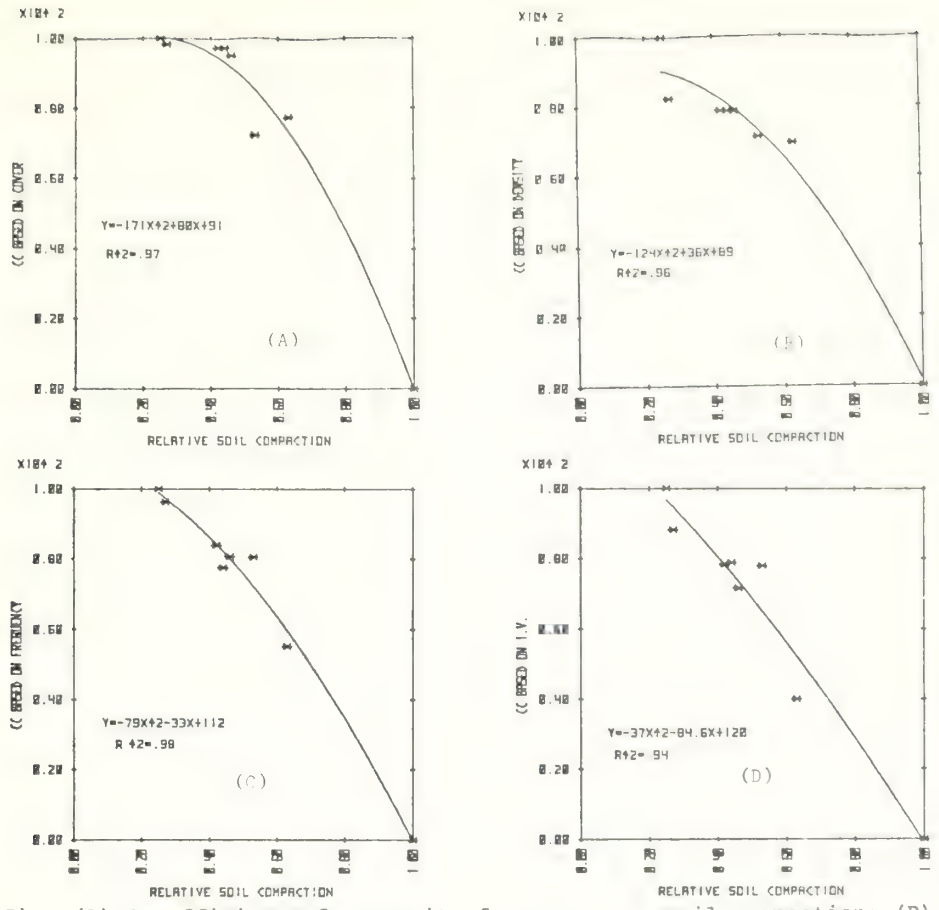

FIGURE 2 (A-D). (A) Cooefficient of community for cover vs. soil compaction; (B) coefficient of community for density vs. soil compaction; (C) coefficient of community for frequency vs. soil compaction; (D) coefficient of community for I.V. vs. soil compaction.

TABLE 3. Coefficient of community (CC) and stand compaction.

Stand No.	1	2	3	4	5	6	7	8
Relative soil compaction*	0.25	0.27	0.42	0.44	0.46	0.53	0.63	1.00
CC								
**c	100	98.3	97.4	97.4	95.2	72.5	77.5	0.0
d	100	82.3	78.9	78.9	78.8	71.5	69.7	0.0
f	100	96.3	83.9	77.5	80.7	80.5	55.2	0.0
I.V.	100	38.2	78.3	78.8	77.6	71.9	40.0	0.0

*Relative soil compaction equals stand soil compaction/soil compaction of most compacted stand (No. 8).

** c = relative cover; d = relative density; f = relative frequency; I.V. = importance value.

may be instances where, perhaps, a particular attribute is not that responsive to environmental changes or trampling stress. For example, relative frequency values may not change either significantly or systematically as soil compaction increases, but relative cover or density values may. The use of importance values may be the best attribute to use when it is not known what species attribute values are most responsive or when individual species vary in their response, since importance values equally weight relative frequency, density and cover values. The disadvantage in using importance values is that they tend to obscure aspects of behavior between species, as the values can decrease with some species even though the species are represented in a majority of stands.

The variable response of individual species attributes and the systematic decrease of CC to soil compaction indicates that new plant communities develop as a result of a change in environmental stress. Ecosystems have the ability to adjust to changing conditions, and if one or several species is removed or experiences changes in attribute values, the ecosystem will adjust, or attempt to adjust, until a new stable condition exists. Because the environmental gradients change in a complex manner when the ecosystem is disturbed by even a single stress, it would seem likely that some new stable condition may not be the same condition that existed prior to the stress.

Since soil compaction measurements are easily acquired and are a function of human use within an area, the correlation of soil compaction with community coefficients may aid land managers in predicting vegetative response as a function of human use in wild areas. This approach may be useful when visitor use data is poor or not in equilibrium with vegetative response. A logical next study would be to determine, perhaps under experimental conditions, the effect of visitor use numbers as they influence soil compaction. This may enable resource managers to then predict vegetative community change as a function of visitor use. This approach would appear to be useful where past and present visitor use data are poor or when visitor use patterns do not remain constant. It would also be desirable to assess change in correlation coefficients for CC versus soil compaction by accounting for significant indirect trampling effects such as changes in exchangeable cations or organic matter, etc.

REFERENCES CITED

BAYFIELD, N. G. 1971. A simple method for detecting variations in walking pressure laterally across paths. J. Appl. Ecol. 8:535-550.

BURDEN, R. F., and P. F. RANDERSON. 1972. Quantitative studies of the effects of human trampling on vegetation as an aid to the management of semi-natural areas. J. Appl.Ecol.9:439-457.

CAIN, S. A. 1959. Manual of vegetation analysis. Huper, 325 p.

CHAPPELL, H. G., J. F. AINSWORTH, R. A.D. CAMERON, and M. REDFERN. 1971. The effect of trampling on a chalk grassland ecosystem. J. Appl.Ecol. 8:869-882.

DALE, D., and T. WEAVER. 1974. Trampling effects on vegetation of the trail corridors of north Rocky Mountain forests. J. Appl. Ecol. 11: 767-772.

FRALEY, L., JR., and F. W. WHICKER. 1973. Response of shortgrass plains vegetation to gamma radiation-I. Chronic irradiation. Radiat. Bot. 13: 331-342.

GREIG-SMITH, P. 1964. Quantitative plant ecology. Butterworth, London, 256 p.

LAPAGE, W. 1967. Some observations on campground trampling and ground cover response. U.S. Forest Service Research Paper, NE-68.

MUNZ, P. A. 1964. A California flora. University of California Press, Berkeley, 1681 p.

SCHOFIELD, J. M. 1967. Human impact on the fauna, flora, and natural features of Gibraltar Point. In the Biotic Effects of Public Pressures on the Environment, ed. by E. Duffey, 106-111. The Nature Conservancy, Monks Wood Symposium, No. 3.

VAN WAGTENDONK, J. 1976. Research Biologist, National Park Service, Yosemite National Park, CA. Personal communication.

WAGER, J. A. 1964. The carrying capacities of wildlands for recreation. Forest Science Monographs, 7. Washington, D.C.

WILLARD, B. E., and J. W. MARR. 1970. Effects of human activities on alpine tundra ecosystems in Rocky Mountain National Park, Colo. Biological Conservation, 2, 257-265.

WOODELL, G. M., and A. L. REBUCK. 1967. Effetcs of chronic gamma radiation on the structure and diversity of an oak-pine forest. Ecol. Monographs 37, 53-69.

GEOLOGY, SOILS, AND RECREATIONAL LIMITATIONS OF BEAR ISLAND, WISCONSIN, APOSTLE ISLANDS NATIONAL LAKESHORE

William L. Kowalski[1]

INTRODUCTION

The purpose of managing national parks or lakeshores "is to provide for extensive public recreation use without deterioration of the natural systems on which this use is based" (USDI 1971). Research programs can produce both scientific knowledge and a resource inventory necessary for park planning and management. This project was initiated for the primary purpose of producing base maps that inventory the soils and geology; and second, to interpret these maps for limitations that may exist for specific recreational uses. Results of this study should allow park planners to locate potential sites for public enjoyment in areas that will best tolerate human impact.

STUDY AREA

Location

Bear Island is located in Lake Superior 4½ miles northeast of the Bayfield Peninsula in northern Wisconsin. It is one of 22 islands that form the Apostle Islands archipelago. Twenty of these islands, plus a shoreline strip on the Bayfield Peninsula, comprise the Apostle Islands National Lakeshore. Bear Island (Figure 1) is situated in La Pointe Township, Ashland County, Wisconsin; Sec 4 and 5, T52N, R3W and Sec 28,29,31,32, and 33, T53N, R3W.

Climate

According to the Koppen climate classification system, the Apostle Islands region is of the 'Dfb' climate code designation. This code characterizes a cold, snowy forest climate, moist in all seasons, with warm summers (Strahler 1970). The mean annual precipitation is 29 inches and the mean annual snowfall, 80 inches. The mean annual frost-free days for the Apostle Islands area is 140 days as contrasted with 120 frost-free days for the mainland (Phillips and McCulloch 1972). This difference reflects the moderating effect of the surrounding Lake Superior waters.

Topography

Bear Island is 2.4 miles long, 1.6 miles wide, oval in shape, and covers 1868 acres. The south end is steeply sloped, rising in a half-mile to the highest point 233 feet above the level of Lake Superior (602 ft asl).[2] The island then grades gradually to 20 feet above lake level at the northern end where cliffs of sandstone outcrops form the shoreline. At the southeastern end a cuspate foreland protrudes several hundred feet into Lake Superior (Engstrom 1972). This foreland and a small beach on the northeast coast are the only points of access. The remainder of the shoreline is steep cliffs of either sandstone or glacial till. The vegetation composition of Bear Island is described by Brown et al. in this publication.

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[2]Above sea level.

Geology

Bedrock. The framework for the Lake Superior basin "was formed in Late Precambrian time when folding, faulting, and the outpouring of lavas resulted in a synclinal structure that dominates the western part of the basin" (Farrand 1969). This basin was filled with sandy sediments, the Lake Superior Sandstones, during latest Pre-Cambrian Era or earliest Cambrian Period (Hamblin 1958). The Lake Superior Sandstones, horizontal reddish sandstones, form the basement rock for all the Apostle Islands (Irving 1880). In northern Wisconsin, along the southern shore of Lake Superior, these sandstones are divided into the Bayfield and Oronto Groups. On Bear Island, the Oronto sandstones are overlain by those of the Bayfield Group (Hite 1968). The Bayfield Group is characteristically quartzose with the average Bayfield sandstones outcrop along the shores of the northeast half of Bear Island often forming wave-eroded cliffs, pillars, arches, caves, and grottos.

Quaternary Period. The Apostle Islands area was glaciated repeatedly during the Quaternary Period. Although Bear Island was probably affected during each glaciation, the present topography is predominantly the result of Late Winconsin glaciation. Doubt exists as to which was the most recent glacial substage to affect the Apostle Islands region. Leverett (1929), Hough (1958, Farrand (1960, 1969), and Saarnisto (1974, 1975) have indicated that the Lake Superior basin was filled with ice during the Valders substage (11,800 B.P.). It has been suggested by Black (1966, 1969) that Valders ice advanced only as far as western upper Michigan, leaving the western end of the Lake Superior basin free of glacial ice during Valders time. Evenson et al. (1976) have proposed the term "Greatlakean" as a replacement for Valderan substage in the Lake Michigan basin because the type-Valders till was demonstrated to be pre-Twocreekan (Woodfordian) in age and the Valders substage only a minor advance of glacial ice. Black (1966) has noted that it is not possible to distinguish Valders till in northwestern Wisconsin based upon its red color. Consequently, the age of the sandy loam till overlying much of the Bayfield sandstone on Bear Island is open to conjecture. However, most workers still conclude that the Lake Superior basin was filled by Valders glacial ice.

No glacial striations or grooving were observed on Bear Island; however, topographic evidence, shoreline observations, and the distribution of till all point to a southwestward movement of glacial ice (Kowalski 1976). The northeast half of Bear Island is almost barren of glacial materials that were deposited directly from the ice. Clays of lacustrine origin, several feet to only a few inches thick, mantle the majority of the bedrock. On the southwest half of the island sandy loam till, many feet in thickness, mantles most of the bedrock. Lacustrine clay deposits cover the till in some areas. Apparently as glacial ice moved southwest over Bear Island, the northeast half was scoured and scraped with little deposition of till occurring. Till deposits are thickest on the southwest half or lee side with respect to glacial movement.

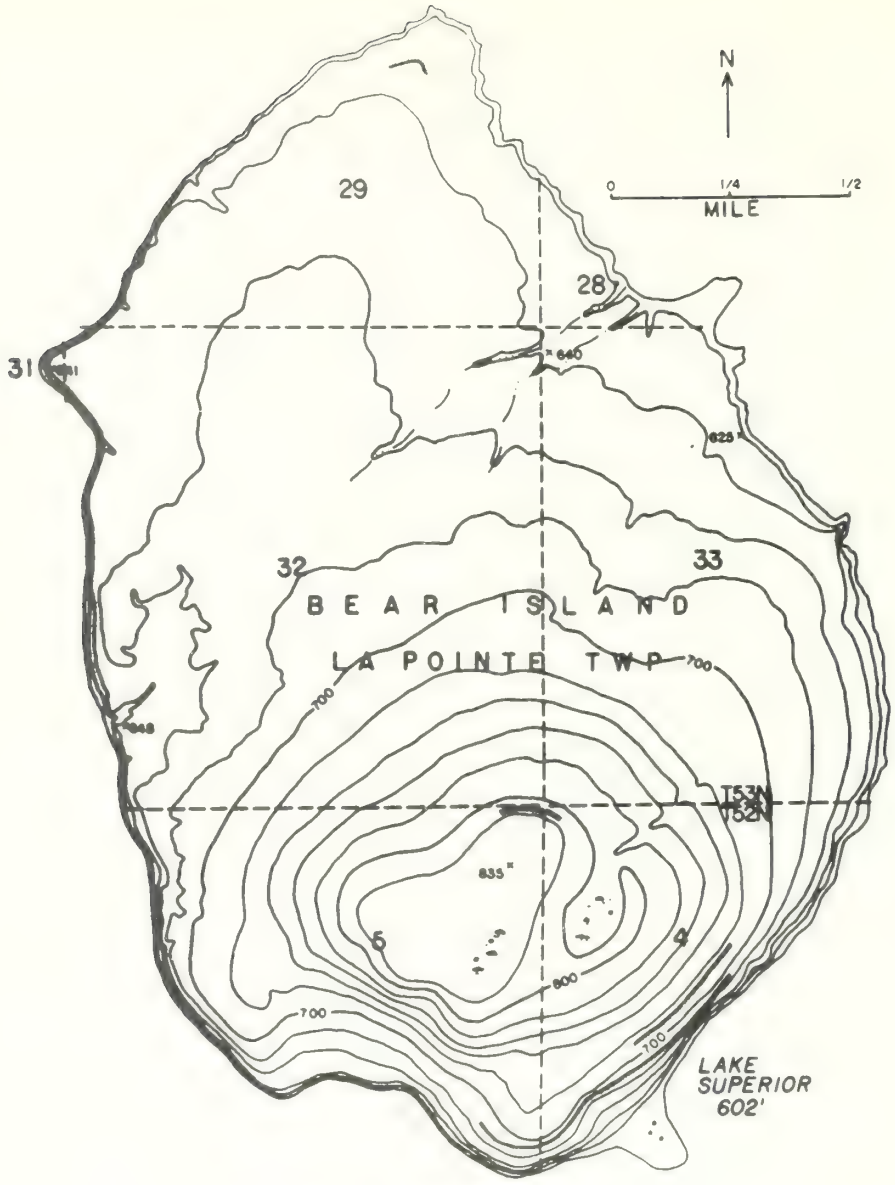

FIGURE 1 TOPOGRAPHIC MAP & ABANDONED SHORELINES (—)

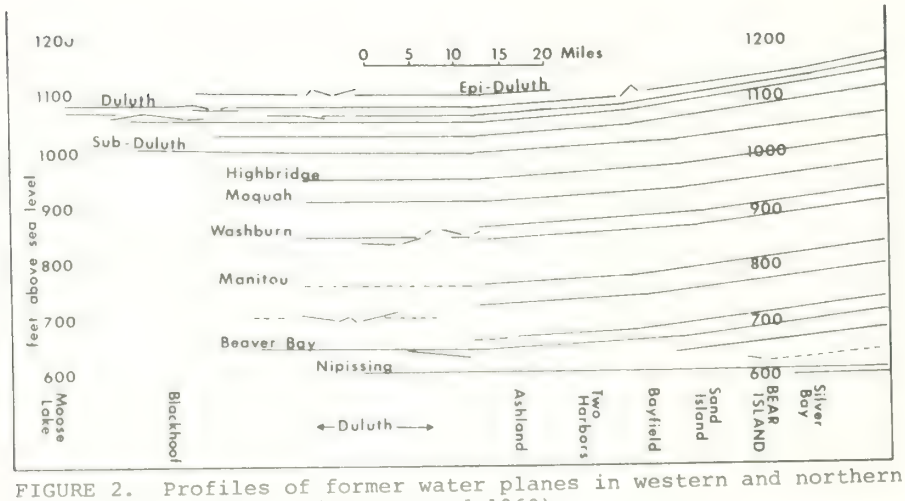

FIGURE 2. Profiles of former water planes in western and northern Lake Superior basin (after Farrand 1960).

During the retreat of the Valders ice sheet, a series of pro-glacial lakes formed in front of the receding ice and progressively occupied more of the Lake Superior basin (Huber 1973). With further retreat of the ice successively lower outlets were opened resulting in a generally downward trend of lake elevation. Following removal of the weight of glacial ice, isostatic rebound (uplift of the earth's crust) further influences lake levels. Retreat of Valders ice about 11,500 B.P. resulted in the formation of the first glacial lake to occupy a major section of the Lake Superior basin; glacial Lake Duluth. Lake Duluth, its highest elevation extending to 1085 feet asl, discharged westward into the Mississippi drainage system (Farrand 1960, 1969). It is during this lake stage that much of the lacustrine clays found mantling the bedrock and till deposits on Bear Island were probably deposited. With the further retreat of the Valders ice sheet to the Huron Mountains area, lower drainages toward the east were opened, initiating the Post-Duluth series of lake stages (11,000 to over 10,100 B.P.). The original elevations before rebound of the Post-Duluth lakes extended from 1007 to below 650 feet asl (Farrand 1960, 1969; Saarnisto 1975). With the advent of lowering pro-glacial lake levels of Post-Duluth Lake Manitou, Bear Island emerged and was water-worked by wave action. Some of the clay sediments were washed away, the sandy loam till was water-worked, and abandoned shoreline features were produced. These features include spits, gravel bars, gravel beach pavements, lagoon basins, terraces, and remnant beach lines.[3] Abandoned shorelines for the Post-Duluth lakes manitou, Beaver Bay and some lower unnamed beaches are evident on Bear Island. According to Farrand's (1969) profiles the highest abandoned shoreline correlates with water levels of Lake Manitou (Figure 2). Due to postglacial rebound this beachline occurs at an elevation of 810 feet asl.[4] A hooked spit of water-worked sand, gravel, and cobbles is evident at just above 800 feet asl east of a small bog, a former lagoon that has filled with organic deposits (Figure 1). The author and Raymond (1975) obtained a core of organic sediments from this bog. However, a radiocarbon date of 9625 B.P. at the organic matter-sand interface appears slightly young for Lake Manitou. Pollen analysis and stratigraphical correlation of this sediment core is needed. A strongly developed shoreline on the southeast of Bear Island occurs at 685 feet asl (Figure 1). In reference to Farrand's profiles, it correlates with a Lake Beaver Bay waterlevel. This shoreline includes a half mile beach occurring below a swale of poorly drained soils easily visible on aerial photographs.[5] Another beachline, though not as strongly developed, located just above the swale of poorly drained soils at 715 feet asl also correlates with a water plane attributed to Lake Beaver Bay. Numerous recessional beaches occur on the northern half of Bear Island as 2-3 foot, sandy ridges overlying lacustrine clay deposits. These were formed during the lowering of Lake Beaver Bay waterlevels. A former shoreline was also noted near the north tip of the island at 635 feet asl. This wave-cut bench can possibly be attributed to the lower unnamed waterlevels of the Post-Duluth stage.

The retreat of glacial ice to the north shore of the Lake Superior basin opened lower outlets, resulting in a generally downward trend of lake elevations. Changes of outlets caused by both erosion and continued glacial rebound affected lake levels that eventually culminated into modern Lake Superior (Saarnisto 1975).

SOILS

Methods

Three primary transects were established crossing perpendicular to the major landforms and drainages. Thirty-four soil pits were dug in the major soils. Samples and profile descriptions were taken as outlined in Soil Survey Staff (1951 and 1960) and were recorded on standard form SCS-213-c 'Soil Woodland Coorelation--Field Data Sheet' of the Soil Conservation Service. Soil profiles were described according to National Cooperative Soil Survey standards as to depth, thickness, boundary, color, texture, structure, consistence, pH and effervescence, roots, cementation, and mottling. Field texture determinations of sampled pits was substantiated in the laboratory utilizing the Bouyoucos hydrometer method and mechanical analysis of the sand fraction. These major soil profile descriptions served as reference points for comparing other soils on the island. Auger borings were taken along the primary transects and several auger transects to a depth of 5-6 feet or to bedrock. Soils at each point of observation were recorded on a base map to facilitate mapping. Reference to aerial photographs further assisted in delineating soil boundaries. Soil slope classes were calculated by utilizing the 10 foot contour interval and scale on the USGS topographic map.

PREVIOUS WORK

The earliest know soil mapping of the Bayfield Peninsula and Apostle Islands took place in 1910 (Whitson et al. 1914). The lowland areas on the northern half of Bear Island were mapped as Superior clay; and the uplands on the southern half, Superior sandy loam. Soils formerly classified as Superior clay are similar to the present day Ontonagon and Hibbing series (red clay soils). The Superior sandy loam soils in this early survey, 10 to 30 inches of sandy loans over red clay, are similar to the present day Superior and Manistee series. Kellogg (1930) states that "in the earlier mapping this distinction was not rigidly nor consistently made and some soils were included in this series that had deeper coverings of sand over the clay than this definition would indicate." In a 1939 soil survey of Bayfield County, Eagle, Sand, York, and Raspberry Islands were mapped (Ableiter and Hole 1961). Several soil associations were delineated. Madeline Island has been soil mapped at the series level (Ashland County Soil and Water Conservation District 1970). A general soil area map of Ashland County makes no mention of the islands within its boundaries (USDA 1971).

Parent Materials, Distribution, and Mapping Unit Descriptions

Soil materials found on Bear Island are characteristic of lacustrine deposits and water-worked glacial drift from active shorelines of lowering

[3]Shetron, S. G. 1974. Soil investigation on Bear Island, Wisconsin, Apostle Islands National Lakeshore. Unpubl. report. Ford Forestry Center, Michigan Technological University, Houghton 49931.

[4]Occurrence of abandoned shorelines was recorded along soil mapping transects. Aerial photographs, the USGS. 10 feet contour interval topographic map, and a barometric altimeter were utilized in determining elevations and in mapping.

[5]8-27-71, 1:15840, infrared black and white, Mark Hurd Aerial Surveys, Inc., 345 Pennsylvania Aveunue, So., Minneapolis, Minn. 55426.

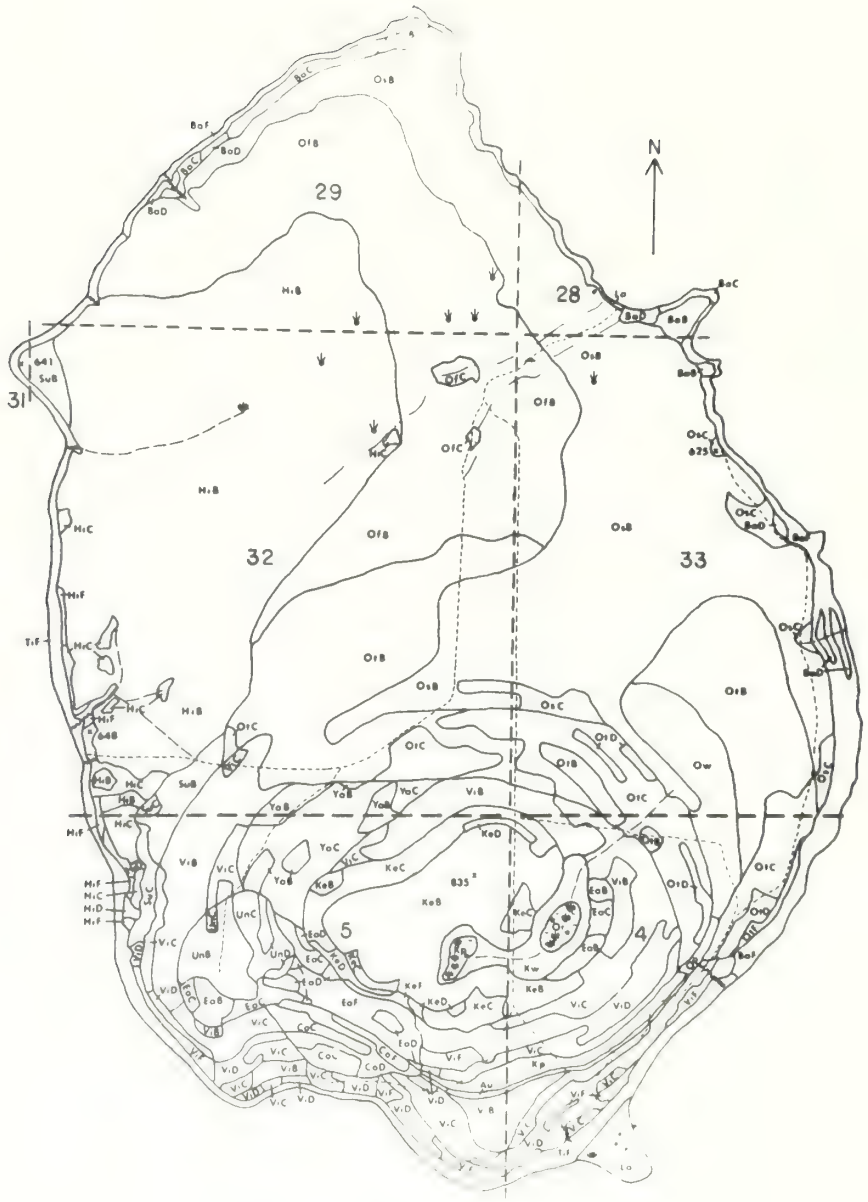
N
29
28
31
32
33
5
4
BaC
BaF
BaD
OfB
OfC
HcB
HcC
HcF
SuB
YoB
YoC
KeD
KeC
KeB
VcB
VcC
VcD
VcF
UnB
UnC
UnD
EoB
EoC
EoD
EoF
KoB
KoD
KoF
OsC
OsD
OsB
OwB
OwC
OwD
KwC
KwB
KpC
KpF
CoC
CoD
CoF
AuB
AuC
AuD
AuF
TcF
TcC
TcD
TcB
LoB
LoC
LoD
LoF
835
825
648
641

FIGURE 3

BEAR ISLAND SOILS MAP
(Scale: 1:18000)

Symbol	Slope	Mapping Unit
Au	B	Au Gres
Ba	BCDF	Misc. Land Type (0-10" to bedrock)
Co	CDF	Croswell
Ea	BCDF	East Lake, acid variant complex
Hi	BCDF	Hibbing
Ke	BCDF	Keweenaw
Kp	B	Keweenaw, poorly drained variant
Kw	B	Keweenaw, somewhat poorly drained variant
La	B	Misc. Land Type (lake sand)
Of	BC	Onota, fine textured variant
Op	B	Onota, poorly drained variant
Or	B	Organic soil
Os	BC	Onota, shallow variant complex
Ot	BCDF	Onota complex
Ow	B	Onota, somewhat poorly drained variant complex
Su	BC	Superior
Ti	F	Misc. Land Type (sandy loam till)
Un	BCD	Undifferentiated area
Vi	BCDF	Vilas-Hiawatha association
Ya	BC	Yalmer-Munising complex

	% slope	
B =	0-6	nearly level to gently sloping
C =	6-12	sloping
D =	12-20	moderately steep
F =	20-45+	steep to very steep

Works & Structures

Buildings ▪

Dock ⊦

Lumber camp ruins ☁

Trails ----------

Drainage

Gully ~~~~

Intermittant stream — — —

Probable drainage unsurveyed — — — — —

Wet spot ⊥ ●

Swamp ⊥ ⊥ ⊥ –

Boundaries & Marks

Section — — — —

Supplementary bench mark x 640

Township — — — —

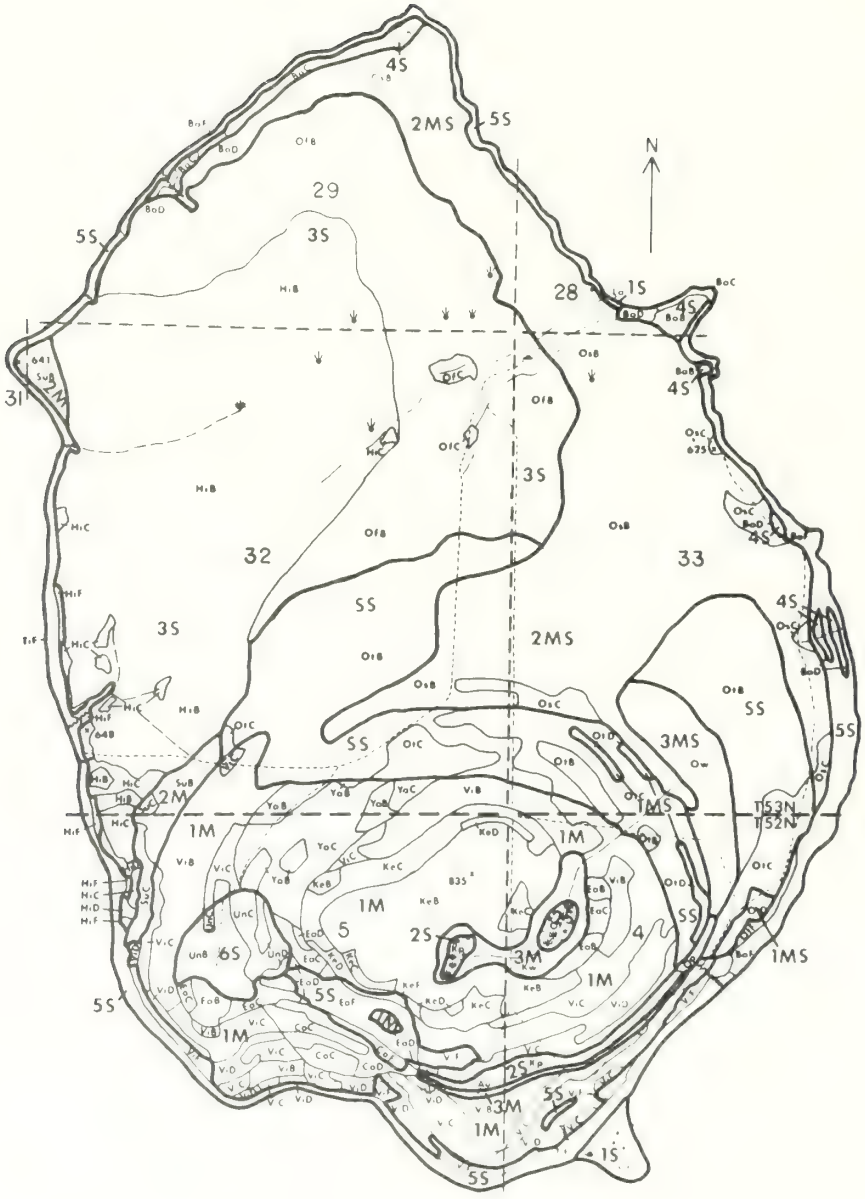
N
29
28
31
32
33
1S
2S
3S
4S
5S
2MS
3MS
1M
2M
3M
5M
6S
SS
1MS
T53N
T52N

FIGURE 4

SOIL LIMITATIONS FOR
PATHS AND TRAILS
(Scale: 1:18000)

SLIGHT TO SEVERE

SS Complex of associated soils, variable in texture (loamy sand, sandy loam, and clay), moderate depth to bedrock (20-40"), level to sloping (0-12%) soils.

MODERATE

1M Sand and loamy sand, level to moderately steep (0-20%) soils.

2M Clay subsoil, level to sloping (0-12%) soils.

3M Seasonally wet, level to gently sloping (0-6%) soils.

MODERATE TO SEVERE

1MS Complex of associated soils, variable in texture (loamy sand, sandy loam, and clay), moderate depth to bedrock (20-40"), moderately steep (12-20%) soils.

2MS Complex of associated soils, variable in texture (loamy sand, sandy loam, and clay), shallow depth to bedrock (10-20"), level to moderately steep (0-20%) soils.

3MS Seasonally wet, complex of associated soils, variable in texture (loamy sand, sandy loam, and clay), moderate depth to bedrock (20-40"), level to gently sloping (0-6%) soils.

SEVERE

1S Loose sand, nearly level (0-2%) misc. land type (lake sand).

2S Wet, level to gently sloping (0-6%) soils.

3S Clay, level to moderately steep (0-20%) soils.

4S Very shallow to bedrock (0-10"), level to moderately steep (0-20%) misc. land type.

5S Steep to very steep (20-45+%) soils and misc. land types.

6S Undifferentiated area.

pro-glacial lake levels. They exhibit evidence of being water laid deposits and are similar to those found on the Bayfield Peninsula. Soil borings revealed that soil meterials are variable in depth (0 to 5 feet or more) over Bayfield sandstone bedrock. Bear Island soils range in texture from sand through clay. On the northern three-fifths of the island the soils are predominantly clays of lacustrine origin, ranging in thickness from several feet to only a few inches, overlying sandstone bedrock. Where the clay cap is absent, soils shallow to bedrock have developed in sand, loamy sand, or sandy loam textured materials. The southern two-fifths of the island is characterized by deeper (5 feet or more) and coarser textured soils originating from water-worked glacial drift. The soil materials are of sand, loamy sand, or sandy loam texture regardless of elevation. The following are general descriptions of mapping units found on the Bear Island soils map (Figure 3). For a more detailed report, the reader is referred to Appendix I (Soil Mapping Unit and Soil Series Descriptions; Particle Size Data) in Kowalski (1976).

(Au) Au Gres--These somewhat poorly drained soils occupy gently sloping areas on sandy lake plains. Surface texture is either sand or loamy sand. Au Gres soils have a seasonally high water table. These soils are of minor extent, comprising less than 1% of Bear Island.

(BA) Miscellaneous Land Type (0-10" to bedrock) --These very shallow miscellaneous land types occupy nearly level to very steep slopes on lake terraces, occurring along the north and northeast shoreline. The 0 to 10 inch layer ranges from thin lacustrine clay deposits to loamy sands either water deposited by receding glacial lakes or weathered in place from the Bayfield sandstone bedrock. The steeper areas associated with this mapping unit consist of sandstone outcrops along the shoreline. This mapping unit comprises 3.5% of Bear Island.

(Co) Croswell--These moderately well drained soils occur on sloping to steep areas on sandy lake plains. Surface texture is sand or loamy sand. The water table is within 3 feet of the surface during wet periods. Croswell soils are of minor extent, comprising less than 1% of Bear Island.

(EA) East Lake, acid variant complex--These well to moderately well drained soils occupy nearly level to very steep slopes on lake plains, intimately mixed with soils which could not be separated individually. East Lake, acid variant soils have developed in 15 to 40 inches of sand or loamy sand overlying acid sand, gravel, and cobbles. Vilas and Hiawatha soils, having developed in lake sands that extend deeper than 40 inches, commonly occur in this mapping unit. Some areas are cobbly throughout the profile. This soil complex comprises 2.1% of Bear Island.

(Hi) Hibbing--These well to moderately well drained soils occur on nearly level to steep slopes. Hibbing soils have formed in lacustrine clay sediments on lake terraces. Surface texture generally ranges from loam to clay although some areas have a thin layer of coarser textured materials deposited during the recession of glacial lakes. Inclusions on Manistee and Superior soils occur where coarser textured materials greater than 10 inches in thickness overlie the finer lacustrine sediments. The somewhat poorly drained Rudyard and poorly drained Pickford soils are inclusions in depressions, along drainages, and on broad flats in some areas. Small wet depressions are indicated on the soils map with the standard wet spot symbol. These soils dry out slowly and are frequently ponded in the spring. This mapping unit comprises 18% of Bear Island.

(Ke) Keweenaw--These well to moderately well drained soils occupy nearly level to steep slopes. Keweenaw soils have developed in water-worked sandstone till. Surface texture is loamy sand overlying sand or loamy sand. The lower subsoil contains an argillic (B'2t) horizon which is weakly cemented in some pedons. Haiwatha soils are an inclusion in some areas. This mapping unit comprises 5.7% of Bear Island.

(Kp) Keweenaw, poorly drained variant--These poorly drained soils occupy nearly level to gently sloping areas. Keweenaw, poorly drained variant soils have developed in water-worked sandstone till of loamy sand texture. The water table is at or near the surface. These soils are of minor extent, comprising less than 1% of Bear Island.

(KW) Keweenaw, somewhat poorly drained variant --These somewhat poorly drained soils occupy nearly level to gently sloping areas. Keweenaw, somewhat poorly drained variant soils have developed in water-worked sandstone till of loamy sand texture. Au Gres soils are a common inclusion. These soils have a seasonally high water table. This mapping unit is of minor extent, comprising less than 1% of Bear Island.

(La) Miscellaneous Land Type (lake sand)-- These well to poorly drained miscellaneous land types occupy level slopes. They occur on the cuspate foreland on the southeast corner of the island and on a small isolated beach along the northeast shoreline. The west side of the cuspate foreland supports a poorly drained marsh habitat. These loose, sandy beach deposits exhibit no profile development. This mapping unit is a minor extent, comprising less than 1% of Bear Island.

(Of) Onota, fine textures variant--These well to moderately well drained soils occupy nearly level to sloping areas. Onota, fine textured variant soils have developed on lake terraces in 20 to 40 inches of lacustrine clay sediments overlying sandstone bedrock. Manistee soils are common inclusions. They occur as 2 to 3 foot sand ridges (recessional beaches) overlying the lacustrine clay deposits. Somewhat poorly drained and poorly drained soils are inclusions in depressions, along drainages, and on broad flats in some areas. Small wet depressions are indicated on the soils map with the standard wet spot symbol. These soils dry out slowly and are frequently ponded in the spring. This mapping unit comprises 15.8% of Bear Island.

(Op) Onota, poorly drained variant--These poorly drained soils occupy gently sloping areas. Onota, poorly drained variant soils have formed in 20 to 40 inches of sandy loan glacial materials overlying sandstone bedrock. The profile is frequently water-sorted containing layers of loamy sand. The water table is at or near the surface. This mapping unit is of minor extent, comprising less than 1% of Bear Island.

(Or) Organic Soil--These very poorly drained, nearly level organic soils occupy a former lagoon basin at 800 feet asl in the southeast. They have developed from black spruce, tamarack, labrador-tea, leatherleaf, and sphagnum moss. The water table is at or near the surface. Sandstone bedrock is above 60 inches along the western outer fringe of this soil area. Organic soils are of minor extent, comprising less than 1% of Bear Island.

(Os) Onota, shallow variant complex--This well to moderately well drained, nearly level to sloping mapping unit contains intimately mixed, associated soils that could not be separated indi-

vidually. An unnamed soil and Onota, shallow variant comprise the majority of this mapping unit. The unnamed soil consists of thin lacustrine clay deposits overlying sandstone bedrock at 10 to 20 inches. Onota, shallow variant soils have developed in 10 to 20 inches of sandy loam glacial materials overlying sandstone bedrock. These soils frequently have a thin loamy sand surface layer deposited during the recession of glacial lakes. Deerton, shallow variant soils, 10 to 20 inches of sand or loamy sand overlying sandstone bedrock, occur within this soil complex. Somewhat poorly drained or poorly drained soils occupy depressional areas or natural drainways. Numerous sandstone fragments and slabs occur on the surface and throughout the profile in some areas. This mapping unit comprises 17.9% of Bear Island.

(Ot) Onota complex--This well to moderately well drained, nearly level to moderately steep mapping unit contains intimately mixed, associated soils that could not be separated individually. An unnamed soil and Onota soils comprise the majority of this mapping unit. The unnamed soil consists of thin lacustrine clay deposits that are frequently underlain by sandy loam glacial till overlying sandstone bedrock at 20 to 40 inches. It is similar to Onota, fine textured variant. Onota soils have developed in 20 to 40 inches of sandy loam glacial materials overlying sandstone bedrock. These soils frequently have a loamy sand surface layer deposited during the recession of glacial lakes. Deerton soils, 20 to 40 inches of sand or loamy sand overlying sandstone bedrock, occur in this soil complex. Somewhat poorly drained or poorly drained soils occupy depressional areas or natural drainways. Thus mapping unit comprises 13.6% of Bear Island.

(Ow) Onota, somewhat poorly drained variant complex--This somewhat poorly drained, nearly level to gently sloping mapping unit contains intimately mixed, associated soils that could not be separated individually. An unnamed, somewhat poorly drained soil, Onota, somewhat poorly drained variant, and Deerton, somewhat poorly drained variant soils comprise the majority of this mapping unit. The unnamed, somewhat poorly drained soil consists of thin lacustrine clay deposits frequently underlain by sandy loam glacial till overlying sandstone bedrock at 20 to 40 inches. Onota, somewhat poorly drained variant soils have developed in 20 to 40 inches of sandy loam glacial materials overlying sandstone bedrock. These soils frequently have a thin loamy sand surface layer deposited during the recession of glacial lakes. Deerton, somewhat poorly drained variant soils have developed in 20 to 40 inches of sand or loamy sand overlying sandstone bedrock. This soil complex has a seasonally high water table, frequently being ponded following the spring melt and remaining wet through June. Poorly drained soils are inclusions in depressional areas. This mapping unit comprises 2.3% of Bear Island.

(Su) Superior--These well to moderately well drained soils occupy nearly level to sloping areas on lake plains. Superior soils have developed in 10 to 20 inches of loamy sands to fine sandy loams overlying lacustrine clay deposits. Inclusions of Hibbing soils occur where the loamy sand to fine sandy loam cap is thin or absent. This mapping unit comprises 1.2% of Bear Island.

(Ti) Miscellaneous Land Type (sandy loam till) --These miscellaneous land types occupy steep to very steep slopes along the shoreline of the southwest half of Bear Island. These cliffs of till, rising 10 to 50 feet above Lake Superior, are usually devoid of vegetation. Following the spring melt or after heavy rains, intermittent streams terminate in small, steep gullies along this shoreline. This mapping unit comprises 2.5% of Bear Island.

(Un) Undifferentiated Area--This area occupies nearly level to moderately steep slopes on the lake plain. Much of this mapping unit consists of wet and seasonally wet sands. In some areas, clays are within 5 feet of the surface. This area is primarily lowland forested with northern white cedar and is not recommended for recreational development. This mapping unit comprises 1.2% of Bear Island.

(Vi) Vilas-Haiwatha association--These well drained soils occupy gently sloping to very steep areas on sandy loam lake plains. Vilas soils are predominant and not as well developed as Haiwatha. Haiwatha soils contain a weakly cemented discontinuous ortstein in the subsoil. This mapping unit contains an unnamed soil that is similar to Vilas and Haiwatha with the exception of redder loamy sands occurring in the substratum below 40 to 50 inches. These soils are most common on the southwest portion of the island. Surface textures range from coarse sand to loamy sand. Moderately well drained Croswell or somewhat poorly drained Au Gres soils are inclusions in depressions and along natural drainways. This mapping unit comprises 10.9% of Bear Island.

(Ya)Yalmer-Munising complex--These well to moderately well drained soils occupy gently sloping to sloping areas on lake plains. This mapping unit contains two associated soils that could not be separated individually. Yalmer soils, the most prevalent, have a solum of lake deposited sands 20 to 40 inches thick overlying acid sandy loam till. A strongly cemented fragipan occurs in the upper sandy loam horizons. Munising soils lack the thicker, sandy upper solum. This mapping unit comprises 2.1% of Bear Island.

RECREATIONAL LIMITATIONS

Methods

Maps depicting the soil limitations for recreational uses were prepared using the methods of Montgomery and Edminster (1966). This involved the utilization of the Bear Island soils map as a base map and interpreting the limitations of soil mapping units for specific recreational uses. USDA-SCS Soil Survey Interpretations and USDA-SCS Soil Limitation Guide Sheets were utilized to obtain limitation ratings. Soil areas were usually classified into three groups according to limitations they pose for specified recreational purposes. These groups are:

"None to slight soil limitations--Soil relatively free of limitations that affect the intended use or the limitations are easy to overcome.

Moderate soil limitations--Soils with moderate limitations resulting from the effects of slope, wetness, soil texture, soil depth, plant growth deficiencies, stones, etc. Normally the limitations can be overcome with correct planning, careful design, and good management.

Severe soil limitations--Soils with severe limitations resulting from the effects of steep slopes, high water table, stream flooding, unfavorable soil texture, acidity, large numbers of stones, rocks, etc. Soils rated as having a severe limitation are severe enough to make the use of the soil doubtful for the proposed use. Careful planning and above-average design and management are required. This often includes major soil reclamation work" (Montgomery and Edminster 1966).

Some mapping units, soil complexes containing intimately mixed soils which could not be separated individually, encompass more than one limitation group. Mapping units with similar limitations

were grouped together. Symbols within similar limitation groups further delineate soil characteristics; such as, texture, slope, wetness, depth to bedrock, etc.

Soil Limitations

The kind of soil determines to a large degree the location and type of recreational facilities. Soil surveys are a useful tool for making predictions of soil behavior under various recreational activities. The foremost soil features affecting the utilization of soils for paths and trails are wetness, flooding, slope, surface soil texture, coarse fragments on surface, and rockiness and stoniness. Ideally, soils used for paths and trails are well drained and flood not more than once during the use season. The surface texture is loam or sandy loam and slopes less than 12%. The surface can consist of up to 20% coarse fragments and up to 10% rock outcrops. Soils on Bear Island that meet these criteria occur to only a small extent. The majority of soils have moderate or severe limitations because of texture, wetness, slope, or rock outcrops. The 'Soil Limitations for Paths and Trails' map (Figure 4) groups together the soils with similar limitations. Soils are well or moderately well drained if not listed as seasonally wet or wet.

The foremost soil features affecting the utilization of soils for camp sites and picnic areas are wetness, flooding, permeability, slope, surface soil texture, coarse fragments on surface, stoniness, and rockiness. Ideally, soils used for these recreational activities are well drained with no flooding occurring during the use season. The surface texture is loam or sandy loam and slopes less than 6%. The surface can consist of up to 20% coarse fragments with very few stones and rock outcrops. Soils on Bear Island that meet these ideal criteria occur to only a small extent. The majority of soils have moderate or severe limitations because of texture, wetness, ponding, slope, or rock outcrops. Soil limitations on Bear Island for camp sites and picnic areas are similar to paths and trails (Figure 4), except that camp sites and picnic areas are rated severe for slopes exceeding 12%. Location of camp sites or a picnic area may depend upon access to Bear Island. Most campers desire sites located as close to the lake as possible (Shafer 1968). Only two areas along the shoreline of Bear Island are accessible by boat. The remainder of the shoreline is either steep slopes of till or steep to nearly vertical sandstone cliffs. Boat access is further limited by submerged glacial erratics and subsidence of large sandstone blocks. One area of access is the cuspate foreland at the southeast end of the island. A small isolated beach on the northeast coast is the only other point of access. The majority of land area encompassing these access points is leased by private parties (life lease and 25 year lease).

The foremost soil features affecting the utilization of soils for septic tank disposal fields are wetness, flooding, permeability, slope, and depth of bedrock or impervious (fragipan). Ideally, soils used for septic tank disposal fields are well drained with no flooding occurring. Permeability of a moderate rate is desirable in order for filtering action to occur. Slopes less than 6% are preferable. Slopes exceeding 12% may result in the surfacing of effluent at low points. Over 80% of Bear Island soils are severely limited because of slow permeability, wetness, shallow depth to bedrock, or slope. Soils suitable for the installation of septic tank disposal fields are found on the southern two-fifths of the island. However, because of sand or loamy sand texture, there is a danger of ground water contamination.

CONCLUSION

Further research correlating and dating abandoned shorelines in the Apostle Islands area is needed. For example, wave-cut terraces visible on Oak Island may encompass the entire sequence of Post-Duluth lakes. Other islands of high elevation exhibit similar features. Such research should yield valuable information for determining the chronology of the Post-Duluth sequence of pro-glacial lakes and contribute to National Park Service interpretive programs.

Onota, fine textured variant soils and the unnamed soils occurring within three of the soil complexes discussed in this article were previously undescribed on the mainland of Wisconsin. These shallow, clay soils are wetter than similar deeper soils during extreme wet periods; and in dry periods, more droughty. If these soils continue to occur on other Apostle Islands, new soil series should be established for management purposes

The clay soils (Hibbing; Onota, fine textured variant; and the unnamed shallow, clay soils occurring within soil complexes) present severe management problems. These soils are subject to erosion slowly permeable, frequently ponded during wet periods, slow to dry, and exhibit poor trafficability. Low areas and drainways remain wet throughout the use season. Recreational development of any kind should be excluded from these soil areas. Utilization of existing trails over these soils should be determined by on-site investigation. Their further use would require above-average management. Trails traversing other mapping units should also be investigated on-site, trouble areas ascertained, and future utilization or relocation determined. Opening of trails would require cutting and removal or windthrow, bridging of drainages, marking, and possible rerouting.

Future National Park Service development plans may be obstructed because of the limited points of access to Bear Island (cuspate foreland and northeast beach). Utilization of these access points is further complicated by leases to private parties, their susceptibility to Lake Superior's storms, and the recreational limitations of soils on and adjacent to these areas.

LITERATURE CITED

ABLEITER, J. K., and F. D. HOLE. 1961. Soil survey reconaissance of Bayfield County, Wisconsin. USDA Soil Survey Reconaissance Series 1939, No. 30. U.S. Government Printing Office, Washington, D.C. 77 p.

ASHLAND COUNTY SOIL AND CONSERVATION DISTRICT. 1970. Madeline Island technical soil report. La Pointe Township, Ashland County, Wis. 41 p.

BLACK R. F. 1966. Valders glaciation in Wisconsin and upper Michigan--a progress report. 9th Con. Great Lakes Research Proceedings. pp 169-175.

_____. 1969. Valderan glaciation western upper Michigan. 12th Con. Great Lakes Research Proceedings. pp 116-123.

ENGSTROM, W. N. 1972. Spatial patterns in beach morphology and sedimentology in the Apostle Islands of northern Wisconsin. Ph.D. Thesis, Univ. of Wisconsin. 236 p.

EVENSON, E. B. , et al. 1976. Greatlakean substage: a replacement for Valderan substage in the Lake Michigan basin. Quat. Res. 6: 411-424.

FARRAND, W. R. 1960. Former shorelines in western and northern Lake Superior basin. Ph. D. Thesis, Univ. of Michigan. 226 p.

_____. 1969. The Quaternary history of Lake

Superior. 12th Con. Great Lakes Research Proceedings. pp. 181-197.
HAMBLIN, W. K. 1958. Cambrian sandstones of northern Michigan. State of Michigan, Dept. Cons., Geol. Survey Division. Publ. 51. 146 p.
_____. 1961 Paleogeographic evolution of the Lake Superior region from late Keweenawan to late Cambrian time. Geol. Soc. Am. Bull. 72:1-18.
HITE, D. 1968. Sedimentology of the upper Keweenawan sequence of northern Wisconsin and adjacent Michigan. Ph.D. Thesis, Univ. of Wisconsin. 217 p.
HOUGH, J. L. 1958. Geology of the Great Lakes. Univ. of Illinois Press, Urbana. 313 p.
HUBER, N. K. 1973. Glacial and postglacial geologic history of Isle Royale National Park, Michigan. Geol. Survey Prof. Paper 754-A. 15 p.
IRVING, R. D. 1880. Geology of the eastern Lake Superior district. *In* Geology of Wisconsin. vol. 3. pp 53-238.
KELLOGG, C. E. 1930. Preliminary study of the principal soil types of Wisconsin. Wis. Geol. Nat. Hist. Surv., Bull. No. 77A, Soil Ser, No. 54. 112 p.
KOWALSKI, W. L. 1976. Geology, Soils and Recreational limitations of Bear Island, Wisconsin, Apostle Islands National Lakeshore. Unpubl. MS Thesis, Mich. Tech. Univ. Houghton. 199 p.
LEVERETT, F. 1929. Moraines and shorelines of the Lake Superior region. U.S. Geol. Survey Prof. Paper 154-A. 72 p.
MONTGOMERY, P. H., and F. C. EDMINSTER. 1966. Use of soil surveys in planning for recreation. *In* Soil Surveys and Land Use Planning. Soil Sci. Soc. Am. and Am. Soc. Agron., Madison, Wisconsin. pp 104-112.
PHILLIPS, D. W., and J. W. MCCULLOCH. 1972. The climate of the Great Lakes basin. Climatological Studies No. 20. Atmospheric Environmental Service, Environment Canada. 41 p.
RAYMOND, R. E. 1975. Radiocarbon ages of some glacial and postglacial lakes in the Lake Superior basin. 79th annual meeting Mich. Academy of Science, Arts, and Letters. Univ. of Mich., Ann Arbor.
SAARNISTO, M. 1974. The deglaciation history of the Lake Superior region and its climatic implications. Quat. Res. 4:316-339.
_____. 1975. Stratigraphical studies on the shoreline displacement of Lake Superior. Can. Jour. of Earth Sci. 12:300-319.
SHAFER, E. L. 1968. The demand for water-oriented outdoor recreation, suggestions for handling its increasing managerial problems. Parks and Rec. Feb. pp 23-25 and 57.
SOIL SURVEY STAFF. 1951. Soil survey manual. USDA Handbook No. 18 plus 1962 supplement. U. S. Government Printing Office, Washington, D.C. 503 p.
_____. 1960. Soil classification, a comprehensive system, 7th approximation, plus 1964, 1970 supplements. U.S. Government Printing Office, Washington, D.C. 265 p.
STRAHLER, A. N. 1970. Introduction to physical geography. John Wiley and Sons, Inc. New York. pp 121-135.
U.S. DEPARTMENT OF AGRICULTURE. 1971. General soil areas: Ashland County, Wisconsin. 13 p.
U.S. DEPARTMENT OF THE INTERIOR. 1971. Apostle Islands master plan. 30 p.
WHITSON, A. R., et al. 1914. Soil survey of the Bayfield area. Univ. of Wis. Geol. Survey. Bull 31. Soil Series No. 5.

MOUNTAIN MEADOW MANAGEMENT AND RESEARCH IN SEQUOIA AND KINGS CANYON NATIONAL PARKS: A REVIEW AND UPDATE

Steven H. DeBenedetti and David J. Parsons[1]

INTRODUCTION

Mountain meadows of the southern Sierra Nevada have experienced concentrated use and impact for over a century. Human impact upon the meadows now included within Sequoia and Kings Canyon National Parks originated with the occasional burning activities of aboriginal man (Reynolds 1959; Vankat 1970). Subsequent sources of impact have included sheep and cattle herding, packstock grazing, and hiking and camping. Since the late 1940's, specific efforts have been made to protect and rehabilitate the Parks' meadow resources.

The present study reviews the history of meadow impact and management. Selected examples of typical resource problems are discussed, their management history traced, and the effectiveness of this management action evaluated.

USE HISTORY

The early Indian inhabitants of present day Sequoia and Kings Canyon National Parks undoubtedly had an influence on the areas' meadow communities. This influence is thought to have consisted primarily of the use of fire for hunting and was probably restricted to meadows of the montane and subalpine belts (Driver 1937; Otter 1963).

Large numbers of domestic cattle and sheep first invaded current Park lands during the drought years of 1862-1864 (Burcham 1957). Insufficient forage in the Central Valley and foothill regions of the state drove them into the higher elevations in search of feed. Sheep had soon traversed the entire high country of the southern Sierra (Vankat 1970).

Typical of the numerous accounts of the devastating influence of domestic sheep is that by King (1902) of decimation in the Kern River area:

> The Kern Plateau, so green and lovely on my former visit in 1864, was now (1875) a gray sea of rolling granite ridges, darkened at intervals by forest, but no longer velveted with meadows and upland grasses. The indefatigable shepherds have camped everywhere, leaving hardly a spear of grass behind them.

With few exceptions, domestic sheep were virtually excluded from the present day Parks by 1900 (National Park Service 1901). Grazing of cattle on private lands within the Park boundaries and by Park and concessioner pack and saddle stock continued.

Permit grazing was sanctioned by the National Park Service Act of 1916 (Ise 1961). Due to meat shortages prompted by World War I, a number of meadows within Sequoia National Park were fenced for cattle. Following the War tourist use increased significantly. Conflicts between recreational and commercial stock use together with a shift in Park Service policy led to the elimination of permit grazing by the early 1930's.

The Forest Service, which still controlled the area later to be included within Kings Canyon National Park, allowed permit grazing to continue on their lands. Direct impact by livestock continued in these areas for some time after establishment of the Park in 1940 due to the policy of extending pre-Park permits on a lifetime basis. The final permit for 100 head of cattle in the Roaring River area is yet to be terminated.

Recreational use of pack and saddle stock increased steadily following World War I, peaking in the mid-1930's (Loughman 1967). This resulted in damage to strategic meadows, extending the deterioration initiated during the days of the sheepherders. In more recent years the use of commercial pack and saddle stock for backcountry travel has decreased markedly. However, since much of this difference has been made up by an increase in government use, total stock days appear to have remained relatively constant over the past decade (National Park Service 1976).

The backpacker boom which began in the 1960's (Harper 1976) has brought an ever increasing number of foot travelers to the Parks' high country meadows. Impact associated with camping, including trampling of vegetation, the development and maintenance of paths and trails, and the incidence of camping upon meadows has increased during this period.

MANAGEMENT STUDIES AND DOCUMENTATION

Beginning with the efforts of Sumner in 1936, periodic studies have been made of the conditions of the Parks' meadows. These studies have evaluated the impact of grazing activities as well as the effectiveness of management actions.

The first extensive survey of Park meadow conditions was made by Sumner in 1940 (Sumner 1941). Besides qualitatively evaluating the status of many meadows, he presented an integrated management program which was designed to protect and facilitate meadow recovery with a minimum of inconvenience to visitors, packers, and permit holders. In 1941 and 1951, Armstrong (1942) and Black (1951) conducted detailed qualitative surveys of the conditions of meadows in the Roaring River district of Kings Canyon National Park.

In 1958 Sharsmith (1959) resurveyed the more heavily used meadows previously visited by Sumner. While localized improvement had occurred Sharsmith emphasized the progressive deterioration of Park meadows during the intervening years. Subsequent studies by Bennett (1965) and Strand (1972) have provided a more quantitative basis for the evaluation of impact and recovery for specific areas.

In 1973 and 1974 DeBenedetti (unpublished) coordinated a field survey of 50 strategic Park meadows, all of which had been previously described by Sharsmith (1959) and most by Sumner (1941). A semiquantitative characterization of the species composition, status, and strategic importance of each meadow was made. Human impact such as trails, camps, wallows, and denuded or heavily trampled sites were enumerated. Regions of extensive streambank erosion and disturbance by rodents were identified and border and invading trees described. An extensive, relocatable photographic record was taken and a survey of

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past management actions made for each meadow. This information provides a basis for comparison with past studies in order to evaluate the effectiveness of recent management actions as well as to provide a baseline from which to evaluate future trends.

RESOURCE PROBLEMS

Trampling and Grazing

Trampling by stock hoofs and vibram soles influences the vegetative and edaphic characteristics of a meadow in several ways (Liddle 1975). Degradation of stems, foliage, and roots, alteration of soil properties, and modification of surface topography may affect the cover, composition, erosivity, and moisture relations of a meadow ecosystem (Figure 1). Management problems which may arise from trampling include increased erosion, reduction in the quality and amount of forage, and artificial stimulation of successional change.

Several of these problems were especially acute in the Roaring River area prior to its incorporation into Kings Canyon National Park in 1940. Broken sod, most often the result of early season trampling by cattle was common in several meadows (Sumner 1941; Armstrong 1942). These conditions persisted and in some cases intensified during the first decade of Park administration as Forest Service grazing permits were extended on a life long basis (Sumner 1974; Black 1951). A flexible entry date, reduction in number of stock, and improvement in herding and salting techniques helped to alleviate some of the potential damage. By the mid-1950's cattle had been completely removed from most of the meadows in the Roaring River area.

An example of the improvement which has occurred since this time can be seen in Upper Paradise Meadow (Figure 2). The broken sod and hummocking which was so pronounced in 1951 has partially healed, its former appearance hidden by lush vegetation.

Trampling damage to drier meadow components also occurred locally within the meadows of the Roaring River area. Reduction of vegetation density and cover resulted in the formation of unstable and easily erodable sand blows. Fencing to exclude cattle from such actively deteriorating sites occurred in several meadows. Considerable improvement had occurred by 1951 (Black 1951) and today there remains even less evidence of this past disturbance (DeBenedetti, unpublished).

In the 1940's and 1950's similar, yet less extensive, problems existed in many of the higher elevation meadows of both Parks (Sumner 1941; Sharsmith 1959). Ratliff (1974) attributes the low foliar cover of *Carex exerta* found today in many of these sites to the impact of past grazing and trampling by sheep, cattle, and pack and saddle stock. Though local impact due to trampling may still occur in high elevation meadows, such restrictions as limitations of party size and duration of stay, manipulation of animals with drift fences, and a flexible date for opening grazing season have been responsible for a significant improvement in their overall condition.

The grazing of above ground biomass results in modification of ecological and edaphic characters of a meadow and in physiological stress to individual plants (Strand 1972; Liddle 1975). The relative impact of grazing depends on its intensity, frequency, and timing. It can affect cover and composition as well as interrupt nutrient cycling, a factor that influences plant growth and soil properties (Figure 1). A loss of photosynthetic potential and reduction of carbohydrate storage can have a disastrous effect in high elevation short growing season environments. Management problems that arise from overgrazing include lack of forage and a change in composition toward an emphasis on poor forage species.

Lack of forage has long been noted by backcountry visitors (Dudley 1899, Kings 1902). Sumner (1941) vividly illustrated this point with the following comment about the Sugarloaf Valley portion of the Roaring River area, "To the traveler with pack and saddle stock, however, it is about the same as a plundered food cache to a starving woodsman." Sharsmith (1959) also reported the lack of forage throughout the strategically located meadows of the Parks. While ingrained use patterns and periods of concentrated pressure have continued to result in local lack of forage, the availability and quality of forage is now considered to be much improved (DeBenedetti, unpublished).

Compositional change has been most obvious in meadows at elevations less than 9,000 feet (Sumner 1941; Sharsmith 1959; DeBenedetti, unpublished). Bennett (1965) and Strand (1972) also demonstrated a positive correlation between the abundance of poor forage species and increased grazing pressure in the higher elevation meadows. Strand found marked improvement (compositional change) in meadows protected from grazing during the period 1965-71. This problem needs more attention in the future.

Erosion

The extent of rill, gully, and channel erosion is directly affected by grazing and trampling. The stability of a stream channel or surface drainage network is a function of the interaction between the erosive agent (water), physical and vegetative characteristics, and various disturbance factors. Management problems associated with such erosion include transport of sediment downstream and the general drying of surface soils. The latter can be an important factor affecting encroachment by conifers or senescence of a meadow.

The breaking of sod by trampling results in a honeycombed topography through which small rivulets can flow around the raised drier islands (Figure 2). This development of a drainage network tends to dry out the meadow. A hummocky mosaic of wet and mesic communities succeed where a homogeneous wet vegetation type had previously existed. The removal of vegetation by grazing, which increases the amount and decreases the period of water flow during runoff can accentuate this trend.

Animals in quest of water or green forage together with campers and fishermen can break down channel banks and disturb critical stabilizing vegetation. This increases the potentital for bank erosion which may help to more deeply entrench meadow stream channels during periods of high runoff.

Management programs designed to halt channel entrenchment began in 1948. These included the construction of check dams to detain sediment and the grading and planting with willow cuttings of collapsing stream banks. While numerous checks were washed out or destroyed by stock, the program on the whole proved immensely successful. For example, Upper Sugarloaf Meadow, its gully once reported to be 14 feet deep (Bechtel 1948), was seen to be much stabilized by 1951 (Black 1951). A dozen other meadows on the verge of washing out in the late 1940's have been similarly stabilized (Figure 3).

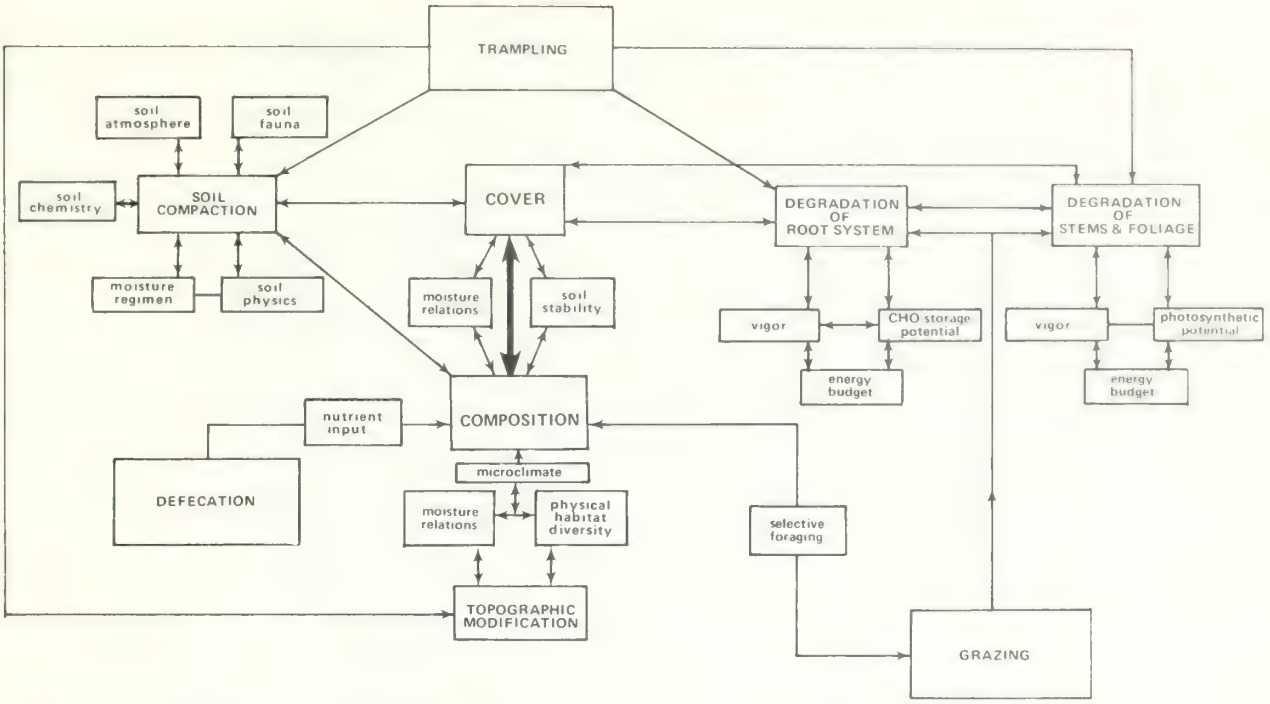

FIGURE 1. Schematic representation of the effects of trampling, grazing, and defecation on mountain meadows.

FIGURE 2. (top) 1951 photo shows broken sod resulting from trampling in Upper Paradise Valley, Kings Canyon National Park. (lower) 1976 photo shows same area after 25 years of protection. National Park Service photographs.

FIGURE 3. (top) 1941 photo shows actively deteriorating gully near south end of Williams Meadow, Kings Canyon National Park. (bottom) 1976 photo shows the same gully following management activities and 35 years time. National Park Service photographs.

FIGURE 4. Parallel trails around Bullfrog Lake, Kings Canyon National Park.

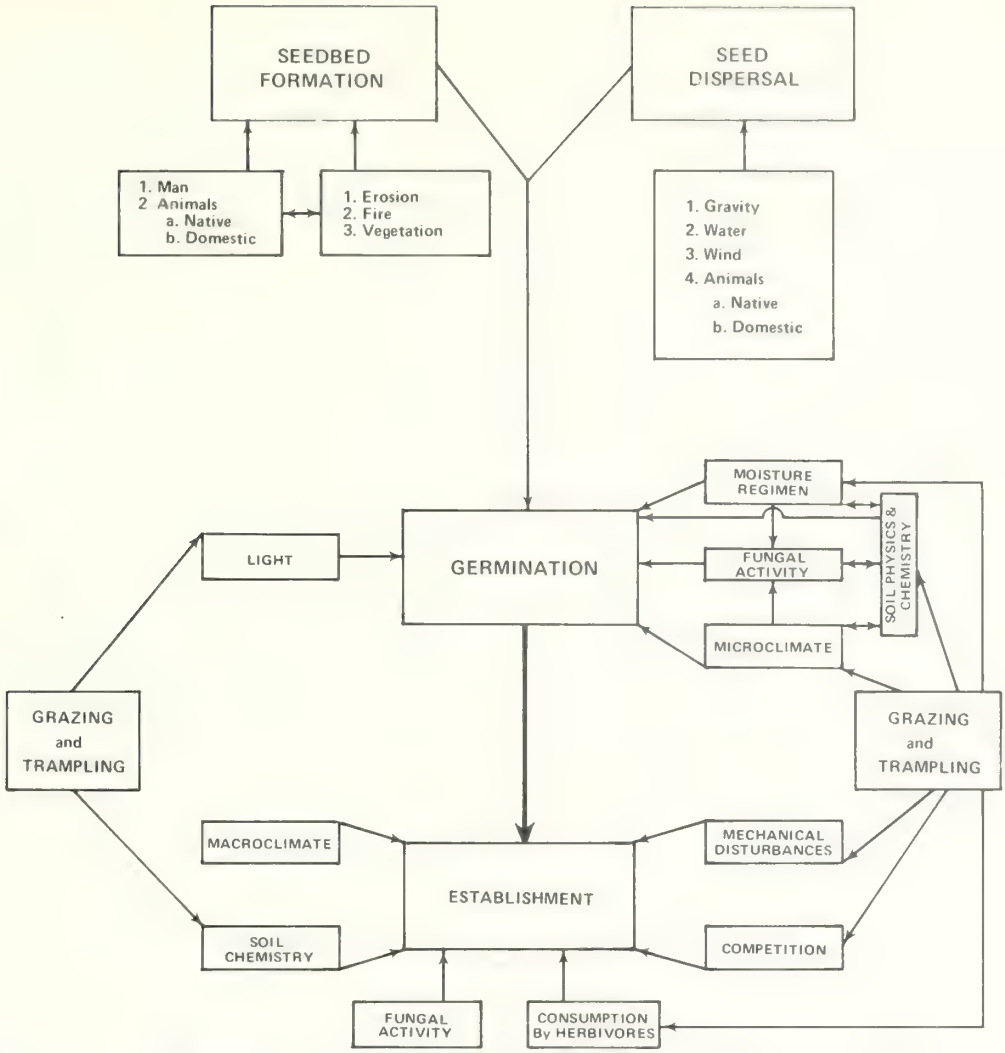

FIGURE 5. Factors affecting seedbed formation, seed dispersal, germination, and establishment of lodgepole pine.

FIGURE 6. Lodgepole pine encroachment was initiated after removal of sheep around 1900 in Sand Meadow, Hockett Plateau, Sequoia National Park.

Trails

Mountain meadows pose an attractive setting for the location of trails. Generally flat, they offer little obstruction to travel, provide openings for scenic vistas, and are almost always good sources of forage. A 1958 survey showed that most strategically located meadows in the Park had major trails located within them (Sharsmith 1959).

Trails through meadows generate significant management problems. Boggy spots quickly degenerate into quagmires as stock and foot travelers alike skirt the periphery. In other places as the sod layer is penetrated by boots and hoofs the trail deepens, often becoming a water course. Parallel trails develop as travelers move over to avoid the rut (Figure 4). This can become especially severe when they erode together forming channels several feet wide. In dry sandy meadows trails become widened as travelers move to the outside to take advantage of the consolidating effect of ground vegetation. Each of these kinds of impact was identified in a number of subalpine meadows of the Parks in 1958 (Sharsmith 1959).

An important part of the meadow rehabilitation and grazing management plan formulated after Sharsmith's 1959 report centered on rerouting trails from meadows in order to correct such problems. Dozens of trails were subsequently rerouted from strategic meadows in the 1960's. Many meadows still have trails which need to be rerouted.

An important problem arising from the rerouting program is the fate of the old treads. Attempts to divert travel from old treads has been successful when the point of separation between new and old trails is well disguised. A number of old treads have also been rocked in an effort to detour use and retard erosion. This practice has met with only partial success since huge rocks provide a poor surface for establishment of vegetation and tend to constrict the flow channel which can actually increase erosion. The one attempt which has been made at filling and sodding of an old treadway shows enough promise that we feel further experimentation with this technique could prove valuable.

The most common treatment for abandoned trails through meadows is to leave them alone. Results have again been variable. More often than not, vegetation has recolonized the banks and bottom of the treadway leaving a vegetated trench with little evidence of surface leveling. Recent work (DeBenedetti and Hill, unpublished) on abandoned trails in Sand Meadow (elevation 8,550 feet) on the Hockett Plateau indicates that *Muhlenbergia* [illegible], *Carex* [illegible], *Aster alpigenus*, and *Ivesia lycopodiodies* are the most important colonizers in mesic sites. On well drained sandy soils revegetation of abandoned trails was more sparse and instability more apparent. *Muhlenbergia filaformis*, *Calyptridium* [illegible], *Potentilla heterosepala*, and *Antennaria* sp. are the most important colonizers in these sites.

Lodgepole Encroachment

Modification of edaphic, vegetative, and physical properties of a meadow by grazing and trampling may accelerate invasions by herbaceous or woody species. Probably the most widespread and controversial invader of Sierran subalpine meadows is lodgepole pine *(Pinus contorta* ssp. *murrayana)*. While natural meadow succession is thought to involve a gradual closing in of the adjacent forest, human related activities may help to trigger or accelerate this invasion (Oosting 1956).

The establishment of lodgepole pine is dependent upon the deposition of viable seed in a satisfactory seedbed, proper conditions for germination, and a favorable environment during the first few years of life (Figure 5). Grazing and trampling may directly or indirectly affect most factors associated with these requisites. For example, seedbeds are formed as densely woven vegetation is broken by stock hoofs and microclimate and soil moisture are affected by removal of vegetation, alteration of microtopography, and soil compaction.

While stock activities tend to favor seedbed formation and improve conditions for germination, establishment may be hindered as seedlings are mechanically destroyed by hoofs. This may account for the observation that trees are frequently "unleashed" after removal of stock from the range. Sharsmith (1950) notes that lodgepole invasion in many Park meadows commenced around 1900, shortly after heavy sheep grazing was terminated (Figure 6). In several meadows of the Roaring River area of Kings Canyon National Park, invasion followed expiration of cattle permits in the mid-1950's.

Management problems resulting from lodgepole encroachment include reduction of potential foraging area and the accelerated senescence of individual meadows. Large portions of several meadows have been claimed by forest in the past 60 years, and noteworthy encroachment has occurred in many more.

Removal of invading trees has been discussed by Park managers since the 1940's (Sumner 1941; Armstrong 1942). Crews actually removed lodgepole from numerous meadows in the 1960's. In most cases the removal of lodgepole pine has produced only temporary success. The unavoidable surface disturbance associated with the removal activities has helped create favorable conditions for immediate recolonization.

Lodgepole removal has been suspended in recent years due to a recognition of the need to separately analyze the causes of encroachment for individual meadows. Further investigation of the relative influence of human activities and such natural forces as rodents and climatic variation on lodgepole invasion of specific meadows is needed.

CONCLUSION

The decreasing use of pack and saddle stock and the virtual elimination of cattle from the backcountry of Sequoia and Kings Canyon National Parks in recent years, together with an increasing attention to and effectiveness of restorative and corrective management programs, have helped the high mountain meadows to show significant recovery over the heavily impacted conditions of the turn of the century. Recent surveys of both specific problems and specific problem areas have provided a basis against which to evaluate this recovery as well as to measure future trends.

As long as future stock and human use is closely monitored such that use numbers and distribution are equitable in both space and time, there should be no reason why current use levels cannot continue. The development of systems to monitor use levels and impact of both stock and people must be given increased attention. Efforts should be made to minimize the number of trails traversing meadows and appropriate corrective actions taken to revegetate abandoned trails. Additional studies are needed on the encroachment of lodgepole pine into specific meadows in order to evaluate whether removal action is warranted.

LITERATURE CITED

ARMSTRONG, JOHN E. 1942. Study of grazing conditions in the Roaring River District, Kings Canyon National Park. Unpub. Natl. Park Service ms. 177 pp.

BECHTEL, STANLEY H. 1948. Sugarloaf Valley soil and moisture control project. Mimeo. report to Natl. Park Service, 2 pp.

BENNETT, PETER S. 1965. An investigation of the impact of grazing on ten meadows in Sequoia and Kings Canyon National Parks. M.A. thesis. San Jose State University. 163 pp.

BLACK, BRUCE. 1951. Soil and moisture report; conditions in the Roaring River Section of Kings Canyon National Park - a ten year pictorial report. Unpub. Natl. Park Service report. 80 pp.

BURCHAM, L. T. 1957. California range land; An historic - ecological study of the range resource of California. California Division of Forestry. Scaramento. 261 pp.

DRIVER, H. E. 1937. Culture element distribution: VI, Southern Sierra Nevada. Anthropological Records 1:53-154. University of California Press, Berkeley.

DUDLEY, WILLIAM R. 1899. Forestry Notes. Sierra Club Bull. 2:290-293.

HARPER, JOHN L. 1974. The Southern Sierra of California: A regional plan for integrated recreational development. Ph.D. dissertation, University of Colorado. 1039 pp.

ISE, JOHN. 1961. Our National Park Policy; A critical history. Johns Hopkins Press, Baltimore. 699 pp.

KING, CLARENCE. 1902. Mountaineering in the Sierra Nevada. Charles Scribner's Sons. New York, N.Y. 378 pp.

LIDDLE, M. J. 1975. A selective review of the ecological effects of human trampling on natural ecosystems. Biol. Conserv. 7:19-36.

LOUGHMAN, MICHAEL L. 1967. National Parks, wilderness areas, and recreation in the southern Sierra Nevada, California: a historical geography. M.A. Thesis. University of California, Berkeley. 193 pp.

NATIONAL PARK SERVICE. 1901. Report of the Acting Superintendent of Sequoia and General Grant National Parks. Unpub. Natl. Park Service ms. 10 pp.

NATIONAL PARK SERVICE. 1976. Plan for the management of backcountry use. Unpub. Natl. Park Service ms. 40 pp.

OOSTING, HENRY J. 1956. The study of plant communities. W. H. Freeman and Co., San Francisco. 440 pp.

OTTER, FLOYD L. 1963. The men of Mammoth Forest. Edwards Brothers, Inc. Ann Arbor, Michigan. 169 pp.

RATLIFF, RAYMOND D. 1974. Shorthair sedge . . its condition in the high Sierra Nevada of California. USDA Forest Service Research Note PSW-293:1-5.

REYNOLDS, RICHARD D. 1959. Effect of natural fires and aboriginal burning upon the forests of the central Sierra Nevada. M.A. thesis. University of California, Berkeley. 269 pp.

SHARSMITH, CARL. 1959. A report on the status, changes, and ecology of backcountry meadows in Sequoia and Kings Canyon National Parks. Unpub. Natl. Park Service ms. 121 pp.

STRAND, STEVE. 1972. An investigation of the relationship of pack stock to some aspects of meadow ecology for seven meadows in Kings Canyon National Park. M.A. thesis. San Jose State University. 125 pp.

SUMNER, E. LOWELL, JR. 1936. Special report on a wildlife study of the high Sierra in Sequoia and Yosemite National Parks. Unpub. Natl. Park Service ms. 64 pp.

SUMNER, E. LOWELL, JR. 1941. Special report on range management and wildlife protection in Kings Canyon National Park. Unpub. Natl. Park Service ms. 288 pp.

SUMNER, E. LOWELL, JR. 1947. Erosion in the Roaring River District, Kings Canyon National Park - A check-up after six years. Unpub. Natl. Park Service ms. 46 pp.

VANKAT, JOHN L. 1970. Vegetation change in Sequoia National Park, California. Ph.D. dissertation, University of California, Davis. 197 pp.

WILDERNESS PROTECTION IN THE HIGH SIERRA: EFFECTS OF A 15-YEAR CLOSURE

David J. Parsons and Steven H. DeBenedetti[1]

INTRODUCTION

Recent years have seen a dramatic increase in public use of our backcountry wilderness areas. This has created a growing concern over how to best manage these areas so as to preserve a semblance of natural conditions while at the same time allowing reasonable public use (Lucas 1971). As a result of efforts to minimize human impact a variety of use restrictions are now in effect in different wilderness areas. These include use quotas imposed either at the trailhead or by individual management zones, restriction of camping to designated sites, closure of certain areas, elimination of wood fires, limits on camping to one or two nights, and strict regulation of stock use and grazing.

While the need for use restrictions is recognized by most wilderness managers, researchers, and users (Taylor 1972; Hendee and Lucas 1973; Fazio 1974) the specific restrictions to be used and their implementation has been the subject of a growing debate (Behan 1974; DeFelice 1975). The basic objection to most such restrictions is that they have been based on subjective judgments of ecological and sociological carrying capacities (Greist 1975). Satisfactory objective criteria with which to measure over-use have not yet been developed. Furthermore, while efforts have been made to measure the sociological and psychological effects of wilderness use restrictions (Fazio 1974; Fazio and Gilbert 1974), little attention has been placed on evaluating the effects of such restrictions on the physical and biological environment.

Bullfrog Lake, at an elevation of 10,600 feet in the Kearsarge Basin of southern Kings Canyon National Park, California, has long been one of the most popular backcountry destinations in the Sierra Nevada. Located within an easy day's journey to the west of the Onion Valley roadhead out of the Owens Valley (Figure 1), this scenic subalpine basin has experienced extremely high use levels for its limited size and fragile nature. By the mid-1950's signs of overuse around Bullfrog Lake included hacked up trees, open can and bottle dumps, multiple criss-crossing trails, and all sorts of abandoned equipment and trash. Shortly thereafter, these problems as well as shortages of firewood and forage led the National Park Service to recognize that unless immediate use restrictions were enforced, this scenic spot would be destroyed forever.

In 1959 all grazing around the lakeshores of the Kearsarge Basin as well as camping at the popular west end of Bullfrog Lake was eliminated. A cooperative cleanup effort with commercial packers and a Sierra Club work party removed over three tons of tin, glass and other debris (Eissler 1959). Encouraged by the effectiveness and public support for these pioneer efforts at wilderness management the Park Service closed the rest of the Bullfrog Lake area to camping in 1961. These restrictions have continued in effect to this day.

In order to evaluate the impact and effectiveness of the use restrictions at Bullfrog Lake, the once heavily used camping area around the lake was compared with a nearby continually heavily used area as well as an adjacent undisturbed forest community. The basic hypothesis was that following 15 years of recovery, the Bullfrog Lake area should show a measurable increase in woody fuels on the forest floor as well as a noticeable recovery of previously heavily impacted campsites. The comparison with both a heavily used and an undisturbed control area should allow for an assessment of the degree of this recovery.

METHODS

A little-visited area less than a kilometer from Bullfrog Lake was used as a control site representing the undisturbed subalpine forest. The popular camping zone on the north side of Charlotte Lake, several kilometers to the west, was chosen as a continually disturbed site approximating the impact that the camping zone at the west end of Bullfrog Lake might once have shown.

Available records were analyzed to evaluate use levels and patterns in the study areas both before and after the Bullfrog Lake restrictions went into effect. Queries were made of the local backcountry rangers in an effort to estimate the amount of trespass camping which now occurs in the Bullfrog area as well as to gain some understanding of the public acceptance of such regulations. Additional information on the latter was obtained from a survey of backcountry visitors conducted in 1975 which questioned the need for and acceptance of various backcountry use restrictions in Kings Canyon National Park (Kantola 1975).

In order to minimize differences due to species composition and relative density, zones of similar forest vegetation in each area were subjectively selected for further study. Each area was sampled with three or four randomly placed plots 30 m on a side. All trees were counted and species and diameter at breast height recorded. From these data each area was characterized in terms of species composition, density, and basal area. In addition, twenty 10.7 m transects were randomly located in each area to assess fuel accumulation. Twigs, branches and logs crossing the transects were counted by size class and converted to kilograms per hectare by the system of Brown (1974).

Within each study area selected campsites or potential campsites were also examined. At Charlotte Lake three of the most heavily used sites along the north shore were studied. Four sites which showed signs of previous heavy use were chosen at the west end of Bullfrog Lake, and four unused but attractive potential campsites were selected from within the control forest. All sites were selected to be comparable on the basis of topography and surrounding tree composition.

For each campsite the central sleeping and cooking area and all perimeter trees and rocks defining the site were mapped. Each tree was examined for nails, saw and axe scars, or other signs of mutilation. In addition, the depth of

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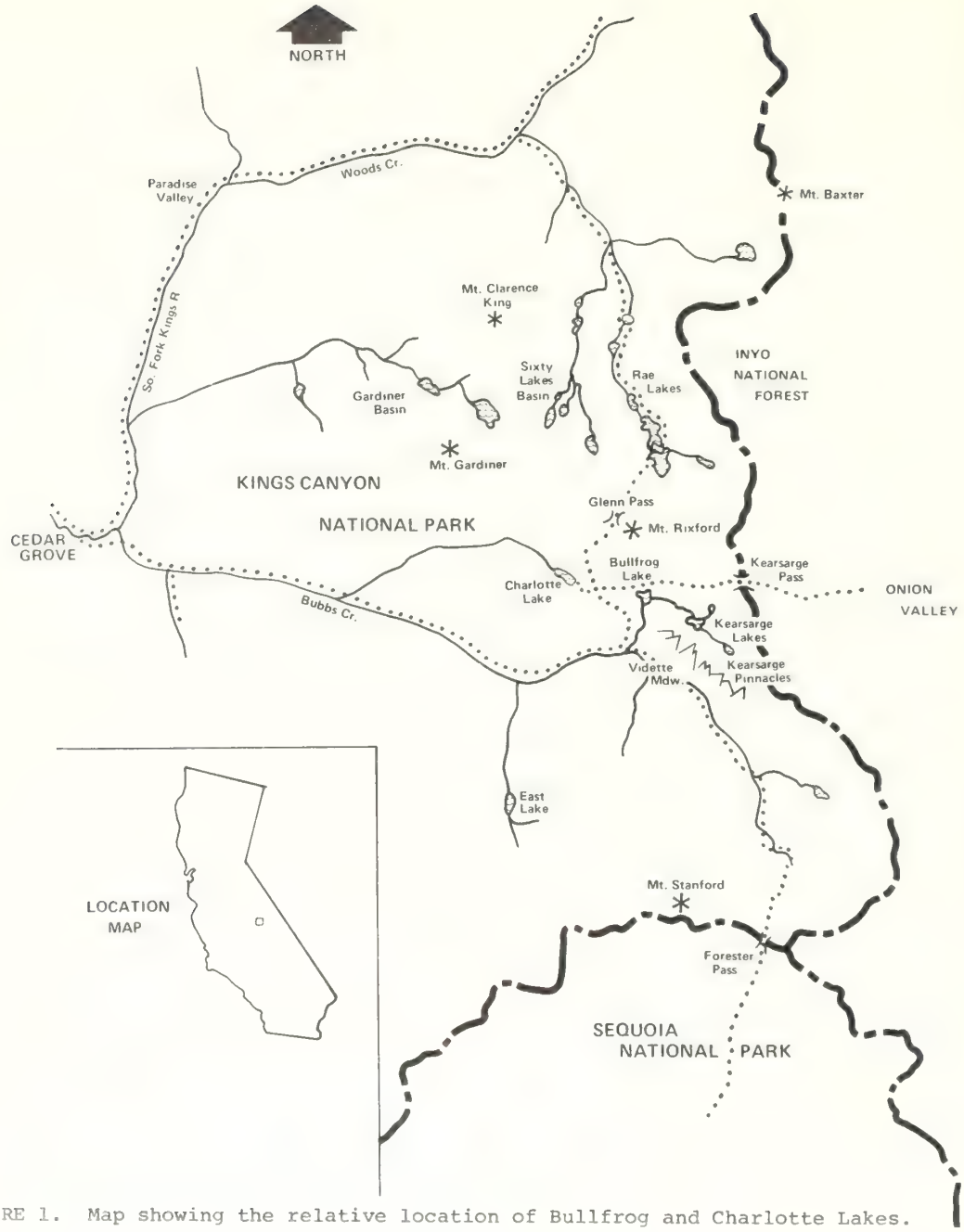

FIGURE 1. Map showing the relative location of Bullfrog and Charlotte Lakes.

litter and duff material was measured at ten points along each of two 6 m transects randomly located within the core camp area. Soil compaction was measured within each campsite by means of a specially constructed penetrometer. The number of blows of a 0.45 kg (1 lb.) weight dropped 30.5 cm (1.0 ft.) required to drive a 0.95 cm (0.35 inch) steel rod 7.6 cm (3.0 inches) into the soil was averaged for from seven to ten spots within each site. This gave a relative measure of soil compaction which could be compared between areas.

RESULTS AND DISCUSSION

Use Patterns and Public Acceptance

The number of persons visiting the backcountry of the high Sierra has increased dramatically during the past century. In the Bullfrog Lake area this use had reached a peak in 1958 when an average of 75 to 100, and as many as 300 people were found camped there (Thede et al. 1961). Following the closure of the popular west end in 1959, overnight use levels at the Lake dropped to an average of ten persons a day (Briggle 1960). Since 1961, overnight camping around Bullfrog Lake has been forbidden. Use has been limited to an estimated 40 to 50 illegal campers a year--many of them before or after the local ranger is on duty, and to day use fishing, and sightseeing parties. This virtual elimination of camper impact coupled with vigorous cleanup efforts has given the area 15 years in which to recover.

Counts in recent years show that use levels around the heavily used north side of Charlotte Lake average about 25 persons a night through the summer, with a peak of up to 70 reached on one or more nights in August (C. Mosely pers. comm.). Similar use levels are thought to have existed for at least the past twenty years. The undisturbed forest in the Kearsarge Basin may receive occasional day use from hikers but suffers virtually none of the impact commonly associated with camp areas.

Public acceptance of the need to institute various use restrictions in order to preserve the Park's backcountry resources has been encouraging. In the case of the Bullfrog Lake closure, both the most severe and longest term use restriction yet employed in the southern Sierra, a minimum of complaints has been received. Kantola's (1975) survey of backcountry visitors to Kings Canyon National Park provides additional support for the concept of restricting use to protect the natural resources. For example, 94.5% of the overnight backcountry users agreed that camping should not be allowed where overuse has damaged the area.

The Forest Community

The three study areas are all characterized by typical subalpine forest communities of widely spaced conifers generally less than 30 m in height (Rundel et al. in press). All three areas show a mix of varying abundances of lodgepole pine (*Pinus contorta* ssp. *murrayana*) and whitebark pine (*P. albicaulis*). The Charlotte Lake site also contains an occasional foxtail pine (*P. balfouriana*). Table 1 summarizes the species compositon, density, and basal area of the forest communities.

Despite such minor differences there is a striking overall similarity in species composition and community structure of the three areas when compared with the overall variability found in Sierran subalpine forest communities (Vankat 1964; Rundel et al. in press).

The accumulation of fuels on the forest floor would be expected to decrease rapidly with increasing levels. In areas that receive heavy use pressure, downed twigs and branches and other woody material suitable for the campfire are used up as fast as they accumulate. In Figure 2 the accumulation of fuels in three size classes up to 7.6 cm in diameter is presented for each area. Representing the prime sizes for kindling and firewood, these values provide a measure of the relative rate of recovery of ground fuels at Bullfrog Lake. The data for each size class as well as for total fuels shows a considerably higher fuel accumulation around Bullfrog Lake than a heavily used Charlotte Lake. The fact that total fuel accumulation in these size classes is still considerably less than around Bullfrog Lake (1,833 kg/ha) than in the control forest (3,246 kg/ha) implies that complete recovery has not

TABLE 1. Basal area and density by species for the overstory forest communities.

	Charlotte Lake	Bullfrog Lake	Control
% Basal Area by Species			
Pinus contorta ssp. *murrayana* (%)	72.4	65.3	63.2
Pinus albicaulis (%)	25.6	34.7	36.8
Pinus balfouriana (%)	2.0	-	-
Total Basal Area (m^2/ha)	64.9 ± 8.06	58.6 ± 8.66	72.3 ± 13.67
% Density by Species			
Pinus contorta ssp. *murrayana* (%)	55.7	42.5	42.3
Pinus albicaulis (%)	36.5	57.5	57.7
Pinus balfouriana (%)	7.8	-	-
Total Density (#/ha)	1,000 ± 215.0	1,276 ± 100.2	976 ± 107.4

*± Standard Error

Total basal area ranges from 58.6 m^2/ha at Bullfrog Lake to 7.23 m^2/ha in the control forest. The relative contribution of each species to the total basal area is quite similar in all three areas.

The density of individual trees and the relative abundance of each species is likewise similar for the three areas. The fact that Bullfrog Lake has the highest density as well as the lowest total basal area suggests that the forest there may be slightly less mature. This idea is further supported by the fact that it shows a somewhat higher percentage of trunks in the smaller diameter classes than do the other areas (unpublished data).

been achieved. This may either reflect insufficient time for complete recovery or the fact that the occasional trespass camping which is known to occur there may be enough to keep the level of fuel accumulation from ever reaching that of an undisturbed forest.

The low levels of all size classes of fuel at Charlotte Lake are characteristic of a heavy use area. The lack of fuel, especially of the larger size classes, often necessitates a long walk and even at times results in the illegal cutting of standing limbs or trees. It is this sort of situation which has necessitated the closure of many popular high elevation areas to wood fires.

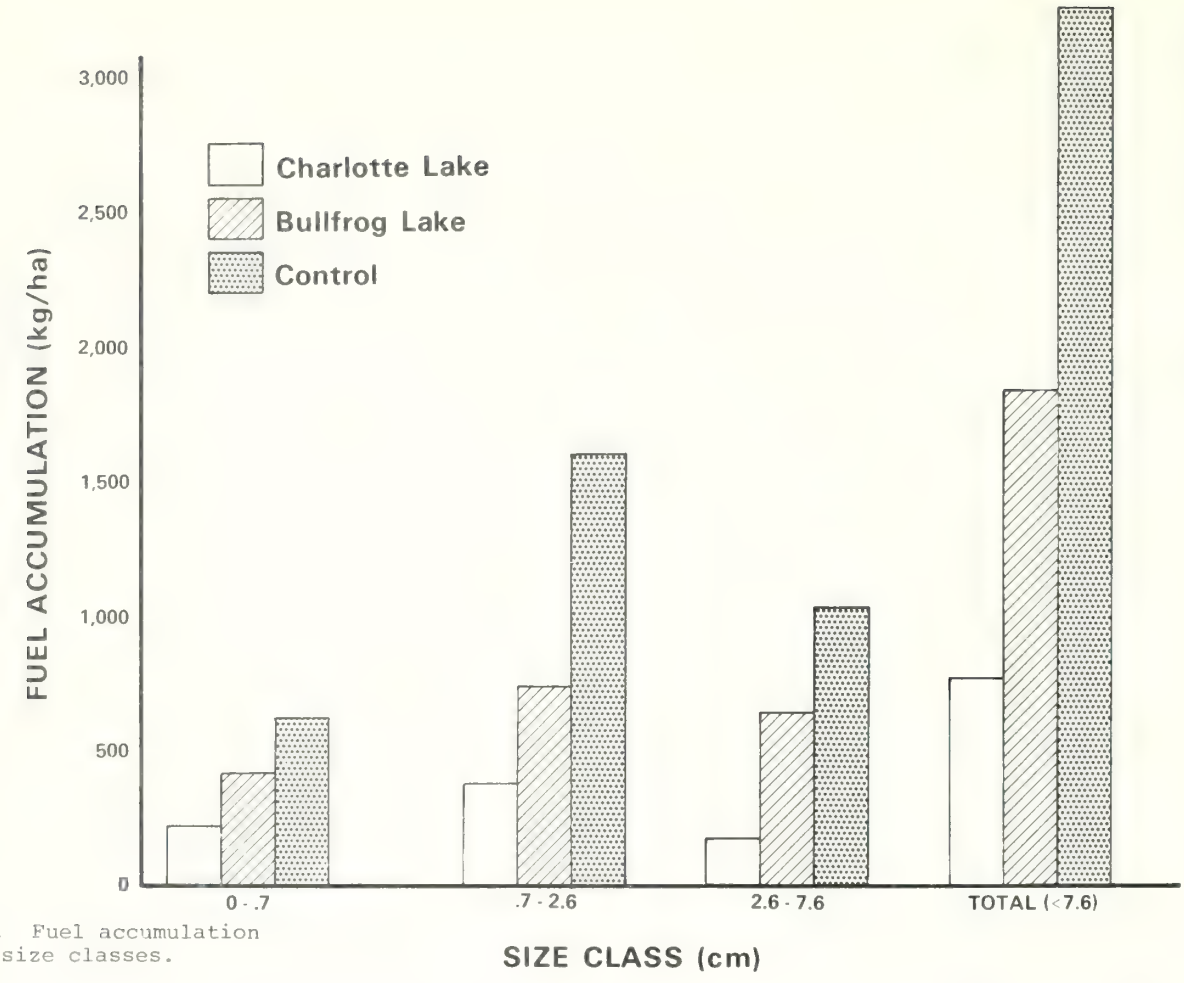

FIGURE 2. Fuel accumulation in three size classes.

A survey of downed logs (greater than 7.6 cm diameter) in each area proved highly variable and was thought to be an ineffective measure of recovery since many of those at the Bullfrog and Charlotte sites had obviously been cut from standing trees. This was further complicated by the fact that much of the naturally fallen larger material in those areas had been cut up and used for firewood.

An additional observation of interest concerns the recovery of the typical fishermen's trails around the lake shore. These trails, so characteristic of high Sierran lakes, show considerable recovery around Bullfrog Lake. While still evident, they are no longer completely denuded as is common in areas of continued heavy use. Shorthair grasses and sedges, bilberry (*Vaccinium nivictum*), laurel (*Kalmia polifolia*), and aster (*Aster alpigenus*) are successfully recolonizing the ground surface and in many places willows (*Salix* sp.) are growing over the trails. Social trails radiating from the campsites towards the lakeshore are now indiscernible at Bullfrog Lake.

Campsite Recovery

The most popular campsites around Charlotte Lake typically showed a heavily used central camp area of from 75 to 150 m^2 which was rimmed by between five and ten trees. The sites at Bullfrog Lake showed a similar configuration although it was considerably more difficult to delineate the central camp area. The control sites were purposefully selected to fall within these general criteria.

The depth of litter (needles and small twigs) present in the central camp areas of each study area is presented in Table 2. This varies from an unmeasurable amount at Charlotte Lake to depths of 2.3 cm and 2.9 cm respectively at the Bullfrog Lake and control forest sites. The essentially bare soil of the Charlotte Lake sites is characteristic of heavily used areas. New litter fall is continually pulverized into the ground, giving a dark hue to the typically light colored sandy surface soil. The fact that the litter accumulation in the once heavily used but now protected campsites around Bullfrog Lake approximates that found in the unused control sites indicates that 15 years is probably sufficient time to accumulate natural levels of litter.

Table 2 also indicates that the 15 years of protection at Bullfrog Lake has allowed a return to near natural levels of soil compaction. The heavily used Charlotte Lake sites show a considerably higher soil compaction than do either of the other two areas.

An examination of trees around the campsites for camper induced mutilations showed 14 of 19 trees around the Charlotte Lake sites with signs of axe cuts, blazes, sawed off limbs, and nails. While 12 of the 32 trees examined around the now protected Bullfrog sites showed similar signs of mutilation, they were in most cases being covered over by new growth. No signs of tree mutilation were found around any of the control sites.

CONCLUSION

From all indications, the 15 years following the closure of Bullfrog Lake to camping in 1961

TABLE 2. Litter depth and soil compaction for central campsite areas.

	Charlotte Lake	Bullfrog Lake	Control
Litter Depth (cm)	0.0	2.3 ± 0.06	2.9 ± 0.26
Soil Compaction (# of hits)	18.9 ± 3.14	10.5 ± 0.60	11.2 ± 0.73

* ± Standard Error

has allowed for a significant recovery of the natural resources of the area. During this time there has been an accumulation of fuels and litter on the forest floor as well as within the once heavily used campsites. Soil compaction in these sites has become less severe and natural growth processes are covering over signs of past tree mutilation. Camper and fisherman trails are revegetating and in general, the area looks much more natural than do nearby areas of continuing heavy impact. While the rates of these various measures of recovery differ, they all show as much, if not considerably more, similarity to the conditions found in the natural, undisturbed forest than those in the still heavily used Charlotte Lake area.

Public acceptance of the need for use restrictions to help protect the backcountry wilderness resource has also been encouraging. This acceptance, together with the proven ability of the resource to respond, must now be coupled with additional experimental studies of use levels, impact, and recovery rates in different community types in order to develop the basis for an effective long range plan for managing our backcountry areas. The judicial use of such restrictions as complete or partial closures and limits on use levels, party size, or length of stay, together with an effective program of minimum impact education, can provide the basis necessary for the long term preservation of our backcountry wilderness resource.

LITERATURE CITED

BEHAN, R. W. 1974. Police state wilderness, a commentary on mandatory wilderness permits. Jr. of Forestry 72(2):98-99.

BRIGGLE, WILLIAM J. 1960. A report on the restrictions imposed on public camping, and grazing, at Kearsarge Lakes and Bullfrog Lake in Sequoia and Kings Canyon National Parks. Unpublished Natl. Park Service ms. 9 pp.

BROWN, JAMES. 1974. Handbook for inventorying downed woody material. USDA Tech. Report INT-16. 24 pp.

DEFELICE, VINCENT N. 1975. Wilderness is for using. American Forests 81(6):24-27.

EISSLER, FRED. 1959. Three tons of tin. Sierra Club Bull. 44(1):5.

FAZIO, JAMES R. 1974. A mandatory permit system and interpretation for backcountry user control in Rocky Mountain National Park. Ph.D. dissertation, Colorado St. Univ. 246 pp.

FAZIO, JAMES R. and DOUGLAS L. GILBERT. 1974. Mandatory wilderness permits: some indications of success. Jr. of Forestry 72(12):753-756.

GREIST, DAVID A. 1975. Risk zoning--a recreation area management system and method of measuring carrying capacity. Jr. of Forestry 73(11):711-714.

HENDEE, JOHN C. and ROBERT C. LUCAS. 1973. Mandatory wilderness permits: a necessary management tool. Jr. of Forestry 71(4):206-209.

KANTOLA, WILLIAM. 1975. A survey of backcountry visitors in Kings Canyon National Park. Unpub. report to Natl. Park Service. 41 pp.

LUCAS, ROBERT C. 1971. The challenge and the response to Forest Service wilderness management in the Rockies. Naturalist 22(3):2-5.

RUNDEL, PHILIP W., DAVID J. PARSONS, and DON T. GORDON. In press. Montane and subalpine vegetation of the Sierra Nevada and Cascade ranges. In Barbour, M. and J. Major (eds.) Terrestrial Vegetation of California. Wiley Interscience. New York.

TAYLOR, RONALD B. 1972. No vacancy in the wilderness. Sierra Club Bull. 67(9):5-8.

THEDE, M. E., E. L. SUMNER, and W. J. BRIGGLE. 1961. A backcountry management plan for Sequoia and Kings Canyon National Parks. Unpub. National Park Service ms. 145 pp.

VANKAT, JOHN L. 1970. Vegetation change in Sequoia National Park. Ph.D. dissertation, Univ. of Calif., Davis. 197 pp.

ANALYSIS OF KAIPAROWITS: POWER PLANT IMPACTS ON NATIONAL RECREATION RESOURCES

Richard V. Giamberdine, Alex R. Carter, Douglas D. Faris, John T. Austin and Joel V. Kussman[1]

INTRODUCTION

In January of 1976, the Denver Service Center, National Park Service, was charged with conducting a study of the potential impacts which would result from the operation of a major power plant proximal to Bryce Canyon, Canyonlands, Capitol Reef, and Zion National Parks and Glen Canyon National Recreation Area. The study was prompted by the proposal of a consortium of utility firms to construct a 3,000 megawatt, coal-fired power generating plant on the Kaiparowits plateau in southern Utah to supply electrical power to Arizona and southern California. Results of the study were to be made available to Interior Secretary Thomas S. Kleppe to aid in determining the desirability of permitting the construction of such a facility.

The National Park Service study team was composed of Richard V. Giamberdine, Regional Planner and Team Captain; John T. Austin, Resource Economist; Alex R. Carter, Environmental Scientist; Douglas D. Faris, Resource Planner; Richard L. Johnson, Economist; and Joel V. Kussman, Wildlife Biologist. Mr. John Byrne, Office of Planning and Compliance, Washington, and Mr. James Isenogle, Utah State Office, served as project coordinators.

The study team was assisted by various professional consultants, familiar with specific subject areas, who were commissioned to supplement, review, and analyze available information in pursuit of the report's purpose.

OBJECTIVES

The primary objectives of the study were to identify and analyze the impacts that development and operation of the proposed 3,000 megawatt coal-fired power plant would have on units of the National Park System proximal to the facility and upon associated recreation values. Environmental components that were assessed included: air quality, scenic quality, natural resources, and socioeconomic resources. Determination of the relationships of Kaiparowits power plant emission levels to Clean Air Act regulations for the prevention of significant air quality deterioration also was a primary study objective.

DESCRIPTION OF THE STUDY AREA

The southern Utah region offers one of the world's most intricately eroded and strikingly beautiful composits of badland topography, mountains, broad mesas, canyons, and rock formations (Kussman 1976). Delicately carved, extremely colorful panoramas dominate the landscape.

Visibility in this area normally exceeds 100 miles. As a result, details of distant landscape features are easily distinguished in this high plateau section of the Colorado Plateau physiographic province. Winters are relatively severe with long periods of extreme cold. Relatively static air masses are prevalent several times during the year, increasing the likelihood of inversion conditions and concomitant high air pollution concentrations in the area.

Two sites were considered for the proposed Kaiparowits power plant. They are located at Four Mile Bench and Nipple Bench in Kane County, Utah. The Four Mile Bench site, situated approximately 22 miles northwest of the Glen Canyon National Recreational Area boundary on the 6000 foot contour interval of the Kaiparowits Plateau, was selected in November, 1973 as the primary site for the plant. The Nipple Bench site, located approximately 12 miles south-southwest of the Four Mile Bench site at the 5000 foot contour interval, was rejected in June, 1973 by the Secretary of the Interior because of its proximity to Glen Canyon National Recreation Area, Grand Canyon National Park, and the Navajo Generating Station. However, it was still considered a viable alternative site for the installation at the time of the study.

Thirteen units of the National Park System, five National Forests, five Indian reservations, and 15 state parks are located within a 150-mile radius of the proposed power plant sites.

ANALYSES AND RESULTS

1. Air Quality

a. Explanation of Air Quality Standards

Pursuant to the Clean Air Act as amended in 1970, regulations to prevent significant deterioration of air quality were promulgated by the U.S. Environmental Protection Agency, which called for the establishment of "classes" of allowable incremental concentration increases in total suspended particulates (TSP) and sulfur dioxide (SO_2) (Table 1). Class I applies to areas in which practically any change in air quality would be considered significant; Class II applies to areas in which deterioration normally accompanying moderate well-controlled growth would be considered insignificant; and Class III applies to those areas in which deterioration up to the national standards would be considered insignificant. Under this regulation, all areas of the country are designated Class II, with provisions for reclassification of an area to accommodate the social, economic, and enviornmental needs and desires of the public. Class I was established to permit added protection to areas of unique scenic values such as units of the National Park System. (Federal Register 1975).

b. Methods and Techniques

Future concentrations of sulfur dioxide (SO_2) and total suspended particulates (TSP) in the park areas were predicted by the EPA-Terrain Model provided by and closely coordinated with Mr. Donald Henderson, Regional Meteorologist, Environmental Protection Agency, Denver, Colorado (Henderson pers. comm. 1976). Additional predictions for SO_2 and nitrogen dioxide (NO_2) were projected by employing a modified National Oceanic and Atmospheric Administration (NOAA) Model which was supplied by Dr. Michael D. Williams (Williams 1976), Research Coordinator for the John Muir Institute for Environmental Studies, Santa Fe, New Mexico (see Figure 1 for the locations of those sites for which 24-hour pollution concentrations were predicted by both models.

[1]National Park Service, Denver Service Center, Denver, Colorado.

TABLE 1. Environmental Protection Agency area designation and deterioration increments.

Pollutant	Class I (ug/m^3)	Class II (ug/m^3)	Class III (ug/m^3)	
Particulate matter (TSP)				
Annual geometric mean	5	10	60	60
24-hour maximum	10	30	150	150
Sulfur dioxide (SO_2)				
Annual arithmetic mean	2	15	80	80
24-hour maximum	5	100	365	
3-hour maximum	25	700	1300	

c. Results

Results of these theoretical analyses indicate that the Class I, 24-hour maximum significant deterioration concentration increment for SO_2 would be exceeded at various points in Glen Canyon National Recreation Area, Bryce Canyon National Park and Capital Reef National Park. Predictions from the NOAA Model indicate that the increment would also be exceeded at Point Imperial in Grand Canyon National Park. Further interpretation of the computer grid printout from the EPA-Terrain Model indicates that, possibly, all of Bryce Canyon National Park, the southern portion of Capitol Reef National Park and the southwest portion of the Glen Canyon National Recreation Area would experience pollution concentrations that exceed the allowable increment for Class I designation (Carter et al. 1976).

The United States does not have a short-term standard or incremental allowance regulating the concentration of NO_2 (U.S. Environmental Protection Agency 1971). However, based on the NOAA Model's predicted concentrations of this contaminant, the objectionable odor of NO_2, for which the threshold is 225 ug/m^3, could be expected in portions of Bryce Canyon National Park, Glen Canyon National Recreation Area and Capitol Reef National Park (Williams 1976).

2. Visual Quality

The prime aspect of this region's scenery is its unique geologic features and landforms set in aura of virtually unlimited visibility, distinctly and characteristically prevailing on the human senses (Giamberdine and Austin 1976a).

Two visual analysis techniques were utilized during the study to quantify the extent of visual impact:

: Visual Analysis of the Kaiparowits Power Plant - This technique was used to determine the visibility of the proposed power plant complex in the surrounding region (an area 60 miles in radius from the proposed sites was analyzed).

: Visual Analysis of the Plume - this technique was used to determine the visual effects stack emissions (plume opacity) would have on observer positions at certain scenic overlooks as the emissions pass between the observer and his field of view.

Visibility of the Plant

a. Methods and Techniques

Computer simulations, using the program VIEWIT, identified those sites in the study area which would have a view of either of the two alternative plant locations (Giamberdine and Austin 1976a). Computer output was then adjusted graphically to identify areas with views of: (1) the power block; (2) the tops of the 600 to 800 foot tall stacks; and (3) the top of a 400 foot plume rise above stacks.

b. Results

Figure 2 illustrates the areas from which the plant or the vertical plume at the plant would be visible if the plant were sited on Four Mile Bench. Considering the area within 60 miles of the plant, the vertical rise of the plume would be seen from 11 percent of the area, and the power block would be visible from 5 percent of the area. The illustration indicates that the power block, the stacks, the plume, and the 7,000-acre development site would be visible from all of the overlooks at Bryce Canyon. High points on the southern end of the Kaiparowits Plateau, Navajo Point, and Spencer Point within the Glen Canyon National Recreation Area would have views of the plant site. The stack and plume rise also would be visible from the Wahweap development in the national recreation area. Other areas affected by visual impacts include such prominent natural landmarks of the region as Canaan Peak, the Aquarius Plateau, Dixie National Forest, Buckskin Mountain, the Sevier Plateau, and a significant amount of Navajo Indian reservation lands in southern Utah and northern Arizona. An independent visual analysis conducted by Utah State University defined the plant's visual prominence to significant natural features and recreation lands south of the Utah-Arizona border on the Kaibab and Paria plateaus. This study also indicated the plant could be seen from areas within Grand Canyon National Park near Lees Ferry.

The visual impact assessment of the proposed Nipple Bench site indicated the 400 foot vertical plume rise could be seen from 9 percent of the area studied. The stack itself would be seen from 7 percent of the area and the power block would be seen from 4 percent of the area (Giamberdine and Austin 1976a).

Visibility of the Plume

a. Methods and Techniques

Using output from the air quality models, computer simulations were employed to project probable changes in visual quality which would occur with operation of the plant. (Giamberdine and Austin 1976b; and Williams 1976). Results were analyzed to determine the effect various meteorological conditions and/or plant operating conditions at either site would have on plume composition and behavior, and the resultant effect on traditionally used, viewer locations within the national parks, monuments, and recreation areas in the region.

b. Results

The output of the model was in the form of

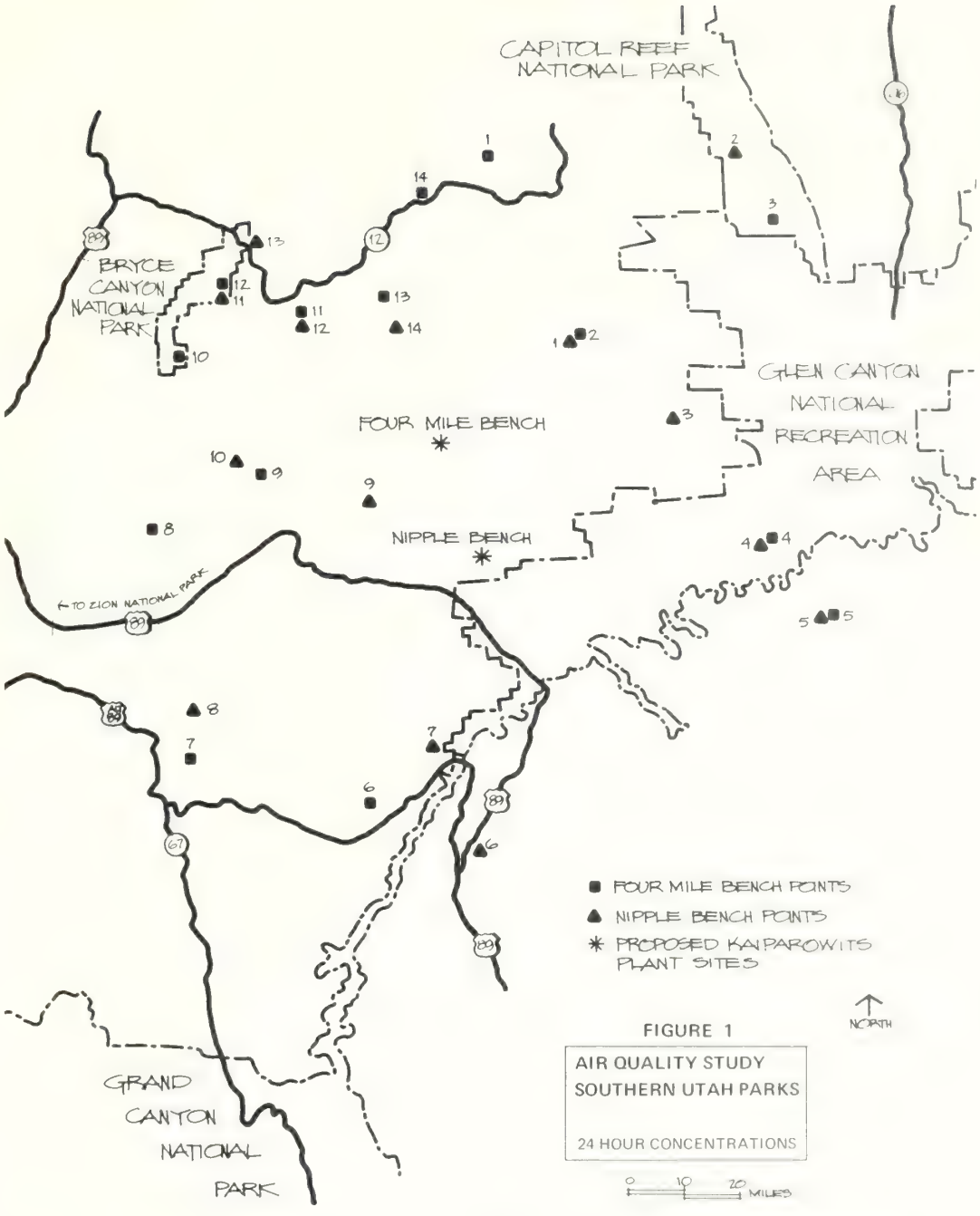

FIGURE 1

AIR QUALITY STUDY
SOUTHERN UTAH PARKS

24 HOUR CONCENTRATIONS

UNITED STATES DEPARTMENT OF THE INTERIOR / NATIONAL PARK SERVICE

opacity contours. Opacity is used in our simulations because it is a quantifiable measure of deteriorating air quality. The following data relate opacity to visual range (Giamberdine and Austin 1976b; and Williams 1976):

: 95% opacity reduces visibility to 23 miles

: 60% opacity reduces visibility to 76 miles

: 20% opacity reduces visibility to 94 miles

In Figure 3, the viewer is looking at the plume as it passes in front of him. The topography under the plume has been superimposed to provide a reference point.

From most viewer sites in Bryce Canyon National Park actual reduction in visibility due to plant operation would be great (2/3 to full reduction) to moderate (1/3 to 2/3 reduction) at least 15 percent of the time. From the principal use area in Glen Canyon National Recreation Area this degree of reduction would occur at least 14 percent of the time. Similar figures were projected for Zion National Park (3%), Pipe Springs National Monument (3%), and for the North Rim of Grand Canyon National Park (3%).

3. Recreation Use and Regional Economics

a. Methods and Techniques

Prior to this study, a survey of Glen Canyon visitors had been made to determine their response to air pollution from the Navajo Plant. From this, estimates were made of the loss in value of a visit due to a decrease in scenic quality. Due to a deficiency in data, assumptions were made as to the number of visits which would

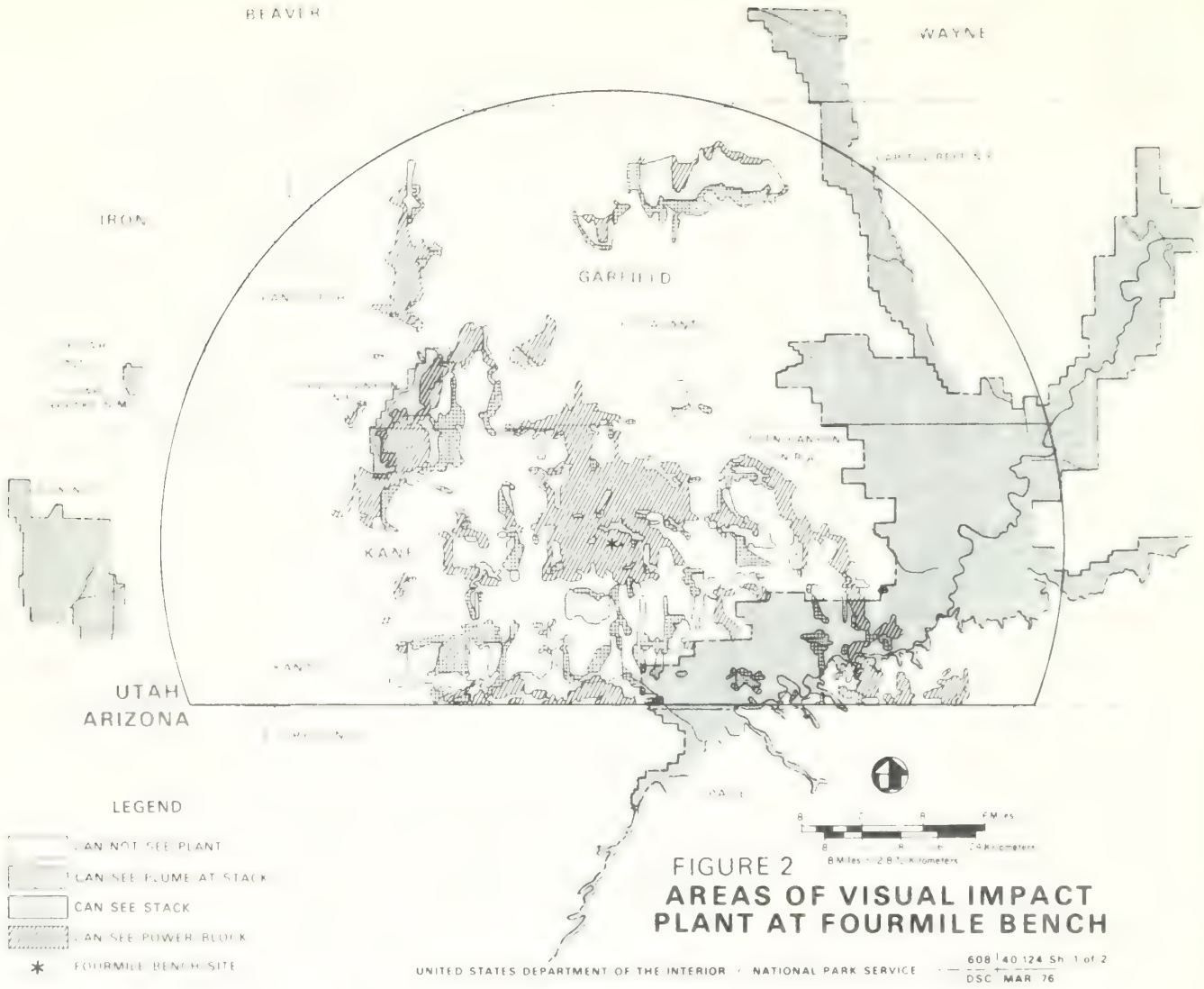

FIGURE 2
AREAS OF VISUAL IMPACT PLANT AT FOURMILE BENCH

not occur due to an increase in air pollution.

b. Results

Research conducted by the Institute for the Study of Outdoor Recreation and Tourism at Utah State University (Hunt 1976) indicated that the five-county region of Beaver, Garfield, Kane, Iron, and Washington is the most tourism-dependent region in Utah. This region, known as the "Color Country," also exhibits the greatest potential for future growth and development of the tourist industry. A ratio relating the importance of recreation and tourism expenditures to individual wealth of visited areas shows that for every one dollar of per capita personal income in Kane County, there is fifty-eight cents per capita of visitor expenditures. This tourism impact factor is much higher than any other Utah county. The tourism impact factor for Garfield County is the second highest in the state at thirty-four cents per capita of visitor expenditures. Anything that would affect tourism would be heavily felt in the economies of these two counties.

A reduction in air quality would have an adverse impact upon visitor enjoyment and use of recreation areas affected by the plant. The ensuing reduction in recreational use would have an adverse effect upon the regional tourism economy.

It is plausible that visitation to the seven federally administered areas in southern Utah and northern Arizona located within 60 miles of the plant would be reduced from a 35-year total of 217,000,000 to 214,000,000, or a loss of 3,000,000 recreation visitor days. This represents a 1.5 percent decrease in potential visitation (Johnson 1976). If this does occur, about $24,000,000 of recreation expenditures would be lost to the regional economy. Furthermore, the recreational value would be reduced by up to $78,000,000 for those public who would visit the recreation facilities in the region regardless of the reduction in air quality.

These negative impacts on tourist values and regional economies could be mitigated if an economically and environmentally feasible alternative plant location could be found. The associated coal mining operation would still provide substantial economic benefits to the Kane and Garfield county area economy. For example, it is estimated that in 1986 the mining operation alone would result in a new employment for 5,025 people, a population increase of approximately 11,306, and a total personal income of 54 million dollars.

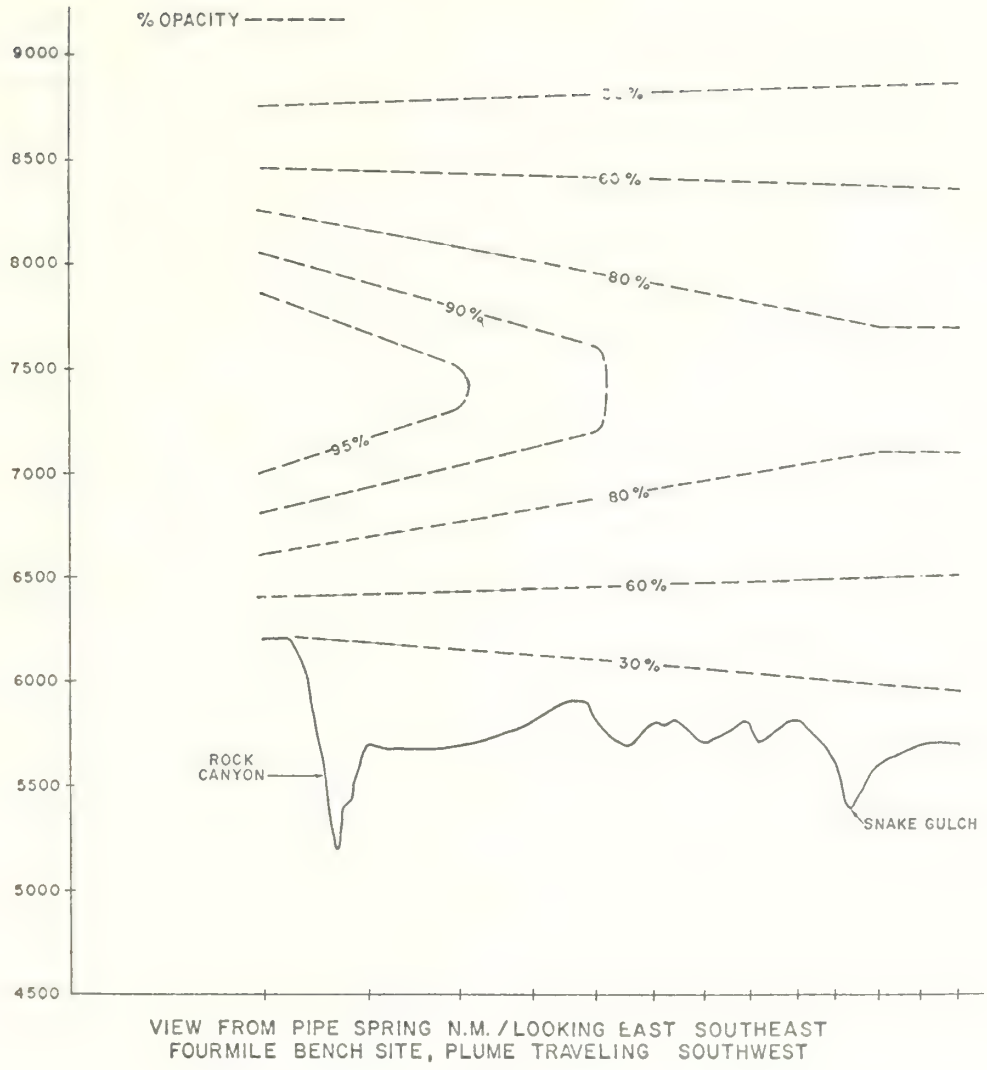

FIGURE 3

This is significant when compared with the 1974 two-county labor force of 2,690 workers, an estimated total population of 6,600 people, and a total personal income of $27,664,000.

4. Natural Resources

a. Methods and Techniques

There was concern that emissions from the proposed Kaiparowits facility might endanger the vegetation and associated terrestrial wildlife in the nearby national parks and recreation areas, since industrial air pollutants have, historically, caused such damage in other regions. Glen Canyon National Recreation Area is situated 5 to 15 miles from the proposed plant sites; other national parks range from 32 to 94 miles from the sites.

Literature pertaining to SO_2, nitrogen oxide (NO), NO_2, hydrogen fluoride (HF), TSP, and other pollutants and their effects on plant life was reviewed. Pertinent works included: Katz and McCollum (1939), Zimmerman (1952, 1955), Thomas and Hendricks (1956), Heck (1968), Costonis (1970), Dochinger and Seliskar (1970), Dreisinger and McGovern (1970), Gilbert (1970), Tingey, et al. (1971, 1973), Hill, et al. (1974), Nash (1974), Nash and Marsh (1975), Hill (1976), and West and Toth (1976).

b. Results

Existing data indicated: (1) injury to the most sensitive plant species in the area would not occur if ground level SO_2 concentrations did not exceed 0.5 ppm for a duration of three hours. (The highest predicted ground level SO_2 concentrations for 10 minutes in the area of the national parks is .059 ppm, thus indicating that there is a safety factor of 8.); (2) plant species proximal to other power plants in similar vegetative areas in the Intermountain West have not sustained observable damage even when exposed to SO_2 concentrations 25-30 times higher than those projected for the Kaiparowits power plant; and (3) it is plausible that damage to vegetation from NO, NO_2, HF, TSP, and other pollutants would not occur because the predicted concentrations from the Kaiparowits facility are well below the concentrations which are known to cause injury.

CONCLUSIONS

1. Air Quality

Class I levels for the prevention of significant deterioration in air quality regulations would be exceeded in all of Bryce Canyon National Park and portions of Glen Canyon National Recreation Area and Capitol Reef and Grand Canyon National Parks. As previously pointed out, the Class I level was established to protect the

environment of unique natural areas such as units of the National Park System.

Theoretical analyses indicate that the ground-level concentrations for SO_2, NO_2, and TSP would be below the National Ambient Air Quality Standards should Kaiparowits become operational at currently designed levels at either the Nipple Bench or Four Mile Bench site. Furthermore, results from the modified NOAA and EPA Terrain models indicate that the proposed facility at either site would not exceed the 24-hour maximum Class II significant deterioration air pollution concentration increments for SO_2 or TSP. The predictions for annual concentrations derived from the EPA model indicate that the maximum Class I significant deterioration increment for TSP would not be violated; however, the annual increment for SO_2 would be exceeded in the vicinity of Canaan Peak and near Right Hand Collet.

The Navajo power plant is presently operational within the area. Should Kaiparowits go forward, it is possible that there would be occasions when the plumes from both plants would impact the same areas. On those occasions, when the plumes were merged and mixed over the same geographic area, the combined concentrations would be greater than those from either plant alone, thereby resulting in synergistic impacts. Both alternate Kaiparowits' sites are in close proximity to national parks and recreation lands as well as national forests and primitive areas, all of which have potential for future redesignation to Class I status. Practically any change in the existing air quality is considered significant in Class I status. The quantitative results from this study indicate that pollution concentrations from the proposed project would preclude such a redesignation.

Air quality simulation modeling for large areas is presently in the developmental stage. Key factors that affect the validity of modeling results are the spatial dimensions of the region modeled, the complexity of terrain within the study area, and the reliability of meteorological data.

The current state-of-the-art for determining small incremental changes in the concentration of specific air pollutants will require continual refinement. The validity of modeling results will continue to be challenged regardless of future improvements in simulation techniques.

Researchers should concentrate efforts toward development of models that will accurately simulate complex terrain and associated meterological conditions. Model testing techniques should be orientated toward achieving more reliable results for small incremental concentration changes in ambient pollution levels.

Meteorological data from remote geographic areas, when available, is generally unsatisfactory for use in air quality modeling. Federal land managers who are aware of proposals that will directly affect the air quality within a natural or wilderness area should consider special programs to collect adequate meteorological data for future use in modeling procedures.

2. Visual Quality

Scenic Resources

Scenic analysis indicated that if the plant were constructed at either of the two proposed sites, it would significantly affect the region's vistas as viewed from Bryce Canyon National Park. Eleven of Bryce Canyon's 12 key observation points would have a direct view of the Four Mile Bench site and its physical components. If located at Nipple Bench, the plant would be a visual intrusion to 9 of the 12 vantage points, but to a lesser degree than the Four Mile Bench site.

Visibility of the Plant and Plume

Analysis of the area within a 60 mile radius of the proposed plant sites indicated that the vertical rise of the plume would be seen from 11 percent of the area and the power block would be visible from 5 percent of the area. The power block, the stacks, the plume, and the 7,000-acre development site would be visible from all of the overlooks at Bryce Canyon National Park.

Current visual analysis techniques were employed to determine when each proposed plant site would be visually apparent from certain key national park features. However, these results did not incorporate the subjective aesthetic preferences of the public. Behavioral science studies by various federal and/or state agencies are being undertaken in an attempt to measure human reactions to scenery. Such research results will find utility in estimating aesthetic impacts where human reactions must be forecasted.

3. Recreation Use and Regional Economics

If the plant were built, there would be a measurable loss of tourism to the area. This would result in a significant economic loss to an area which is highly dependent on tourism. Although less apparent, a much larger loss would be incurred by those who visited the area, but whose experience was decreased by the presence of air pollution and the resulting visual quality impacts.

4. Natural Resources

Project emission concentrations levels will not exceed the threshold level for damage to vascular plants that occur in the subject national parks and recreation areas. As a result, impacts on vegetation and, in turn, on terrestrial wildlife resources were determined not to be significant. It is possible, however, that fumigation episodes could cause localized damage to vegetation and associated wildlife habitat on frequent occasions.

LITERATURE CITED

CARTER, ALEX R., DOUGLAS D. FARIS, and D. HENDERSON. 1976. Predictions of SO_2 and TSP pollutants caused by the Kaiparowits power plant. National Park Service, Denver Service Center: Denver, Colorado. 51 pp.

COSTONIS, A. C. 1970. Acute foliar injury of eastern white pine induced by sulfur dioxide and ozone. Phytopathology 60(6):994-999.

DOCHINGER, L. and C. E. SELISKAR. 1970. Air pollution and the chlorotic dwarf disease of eastern white pine. Forest Science 16(1):46-55.

DREISINGER, B. R. and P. C. MCGOVERN. 1970. Monitoring atmospheric sulfur dioxide and correlating its effects on crops and forests in the Sudbury area. In: Proceedings of the Conference on the Impact of Air Pollution on Vegetation. Toronto, Ontario, Canada. 23 pp.

GIAMBERDINE, RICHARD V. and JOHN T. AUSTIN, 1976a. Scenic intrusion of the Kaiparowits power plant. National Park Service, Denver Service Center: Denver, Colorado.

_____. 1976b. Visual intrusions caused by the Kaiparowits power plant. National Park Service, Denver Service Center: Denver, Colorado.

GILBERT, O. L. 1970. Further studies on the effect of sulfur dioxide on lichens and bryophytes. New Phytologist 69:605-627.

HECK, WALTER. 1968. Discussion of paper: Effects of Oxidant Air Pollutants. J. of Occup. Med. 10:496-499.

HILL, A. C. 1976. Potential for air pollution damage to vegetation in National Parks and Recreation Areas from the Kaiparowits power plant. Department of Biology, University of Utah, Salt Lake. 39 pp.

HILL, A. C., S. HILL, et al. 1974. Sensitivity of native desert vegetation to SO_2 and to SO_2 and NO_2 combined. APCA Journal 24(2):153-157.

HUNT, JOHN D. 1976. Recreation, tourism and energy development in southwestern Utah. Institute for the Study of Outdoor Recreation and Tourism, Utah State University, Logan. 20 pp.

JOHNSON, RICHARD L. 1976. Recreation use and regional recreation industry. National Park Service, Denver Service Center: Denver, Colorado. 23 pp.

KATZ, M. and A. W. MCCALLUM. 1939. Experiments on conifers in their natural habitat. National Research Council of Canada. In: Effects of Sulfur Dioxide on Vegetation. pp. 218-244. Ottawa, Canada.

KUSSMAN, JOEL V. 1976. The significance of southern Utah park resources. National Park Service, Denver Service Center: Denver, Colorado. 59 pp.

NASH, T. H., III. 1974. Lichens of the Page environs as potential indicators of pollution. J. of the Arizona Academy of Science 9(3):97-101.

NASH T. H., III and J. MARSH. 1975. Lichens as air pollution indicators in arid environment. Bull. Ecological Society of Amer. 56(2):60.

OFFICE OF THE FEDERAL REGISTER. 1975. Air Quality Implementation Plans: Prevention of Significant Air Quality Deterioration. Vol. 39, No. 235, Part III.

THOMAS, M. D. and R. H. HENDRICKS. 1956. Effect of air pollution on plants. In: Air Pollution Handbook, ed. P. L. Magill, F. R. Holden, and C. Ackley, pp. 9.1-9.44, New York.

TINGEY, D. T., R. A. REINERT, et al. 1973. Foliar injury responses of eleven plant species to ozone/sulfur dioxide mixtures. Atmospheric environment Pergamon Press 7:201-208.

_____. 1971. Vegetation injury from the interaction of nitrogen dioxide and sulfur dioxide. Phytopathology 61(12):1506-1511.

UNITED STATES DEPARTMENT OF THE INTERIOR. 1976. Analysis of Kaiparowits: Power plant impacts on national recreation resources. National Park Service, Denver Service Center: Denver, Colorado. 47 pp.

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY. 1971. Air quality criteria for nitrogen oxides. Office of Air Pollution Control, Washington, D. C.

WEST, NEIL E. and DIANA I. TOTH. 1976. Ecology of lichens of the arid to semi-arid environments of the Colorado Plateau. Department of Range Science, Utah State University, Logan. 21 pp.

WILLIAMS, MICHAEL D. 1976. Report on Kaiparowits impacts on air quality. John Muir Institute, Santa Fe, New Mexico. 42 pp.

ZIMMERMAN, P. W. 1955. Chemicals involved in air pollution and their effects upon vegetation. Boyce Thompson Institute, Prof. Paper No. 2., pp 124-145. Yonkers, New York.

_____. 1952. Air pollution. In: Proc. of the U.S. Tech. Conf. on Air Pollution. McCobe, McGraw-Hill.

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